JAXA TRMM Science status
End-of-Mission Experiments results from TRMM/PR

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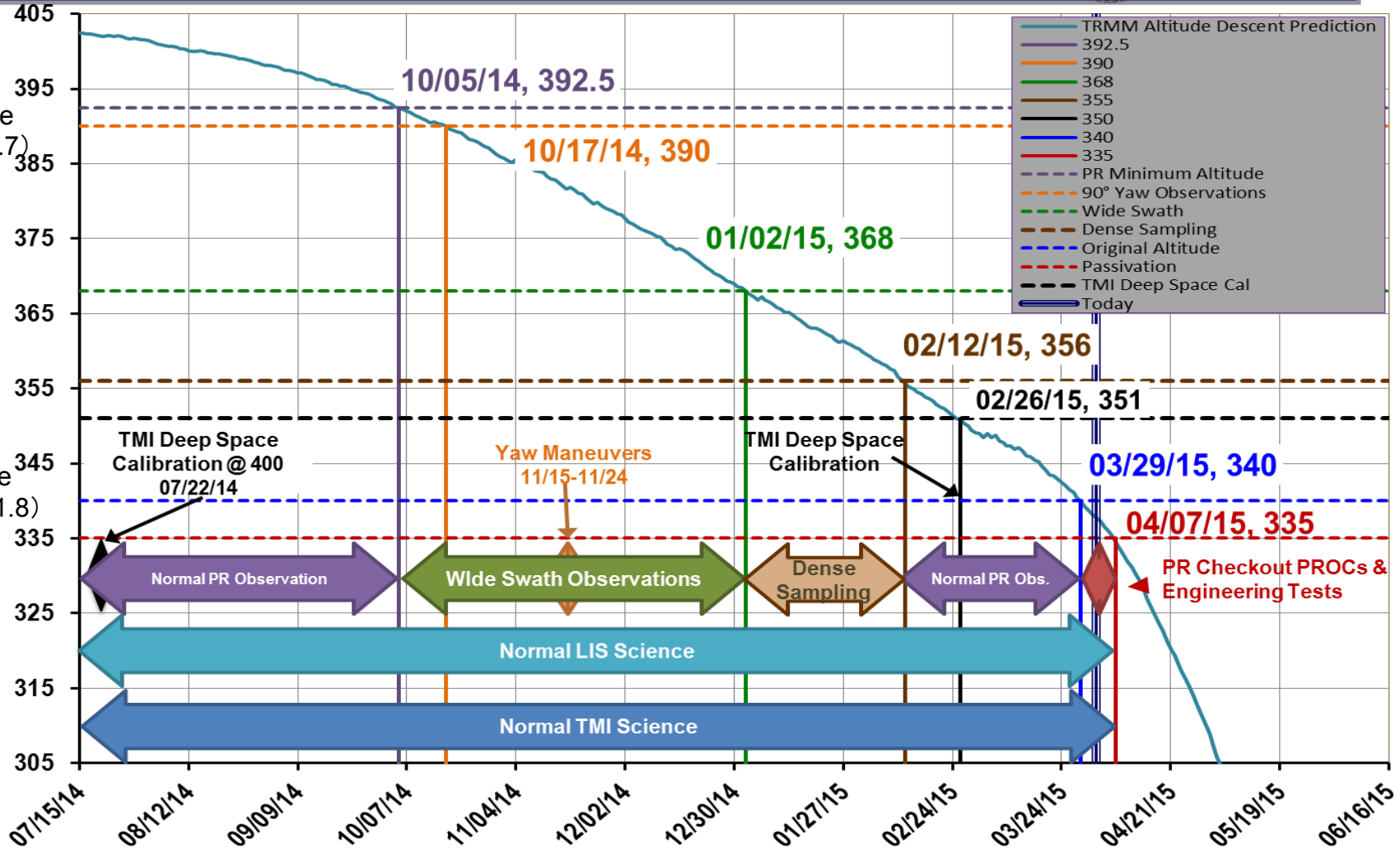
2017.07.14

Satellite altitude (from NASA/FOT's presentation)

nominal altitude
(2001.8−2014.7)

nominal altitude
(1997.12−2011.8)

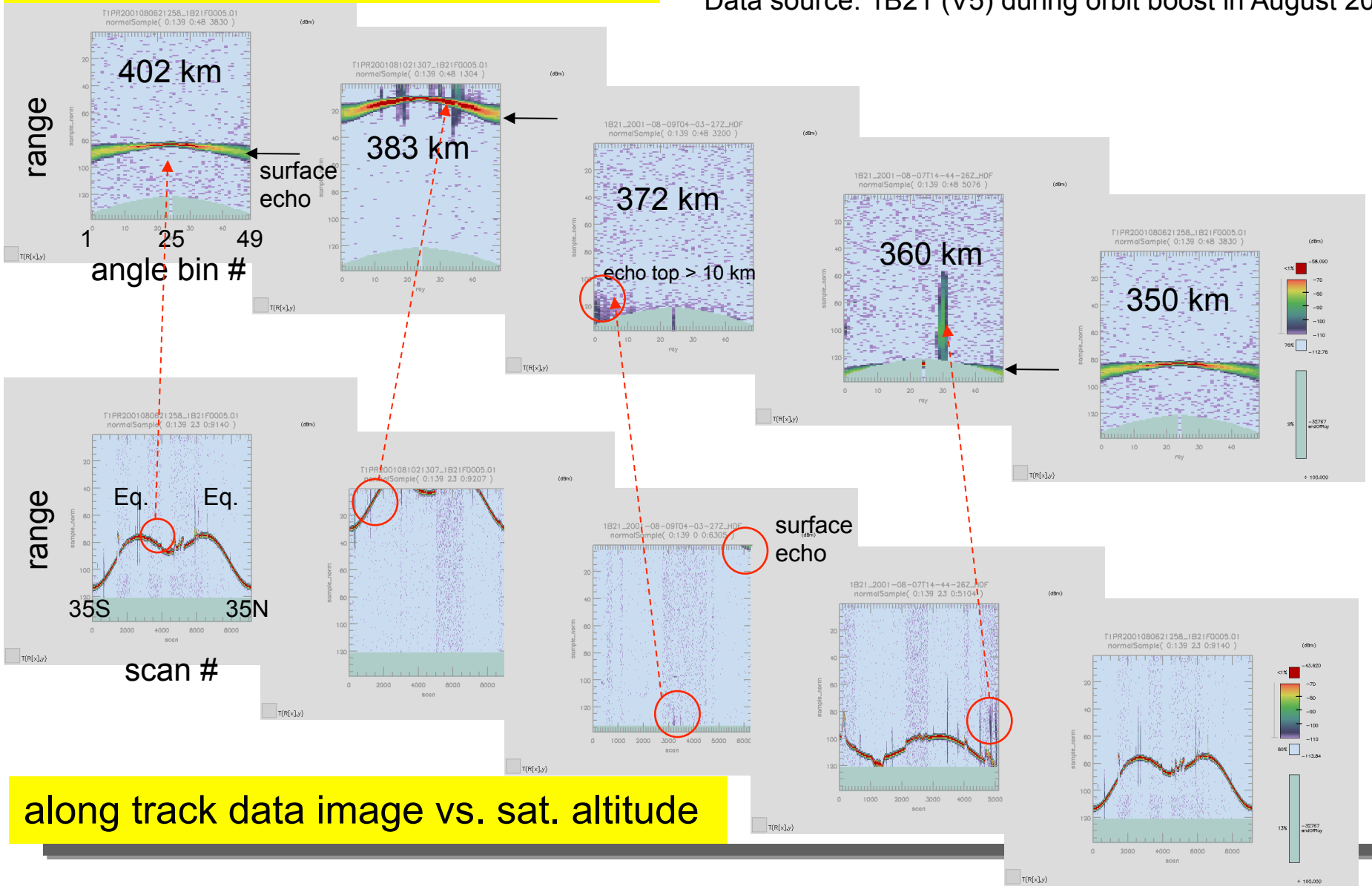


If the solar beta angle is less than 20 degrees, PR's operation was limited only day side of the orbit, because of battery issue.

What PR observes during the descent

scan data image vs. sat. altitude

Data source: 1B21 (V5) during orbit boost in August 2001.



along track data image vs. sat. altitude

Detailed experiment schedule (as Jul. 2014)

		purpose	operation	altitude window(s) or duration	note
1	Nominal observation	1.Comparison with GPM/ DPR. 2. Increase the rain record by radar. 3. Testing GSMaP.	Nominal observation	402.5 to 392.5 km And 355 to 340 km	Retrieved data may be valid until the radar observed up to 5 km in height.
2 b	Dense sampling	Increase the data on the non uniform beam filling effect.	External cal. mode	**357 to 355 km** (10 days)	
2 d	Wider swath experiment	To check the possibility to enlarge the swath	External cal. mode or Nominal obs. Mode	390 to 355 km (11 month)	Need to upload of the phase code for three times according to the satellite altitude.
3 a	90 deg. yaw observation*	To obtain the detailed rain structure and sigma zero from various incident angle.	Nominal obs. mode with satellite yaw angle of 90 deg.	**392 to 390 km** (total 10 days)	4 yaw maneuvers per day and each time about 22 min. observation. Combining with wider scan experiment is preferable.
4	checkout	To obtain the engineering information of PR	Various modes	Below 340 km	Implementation has not been decided.

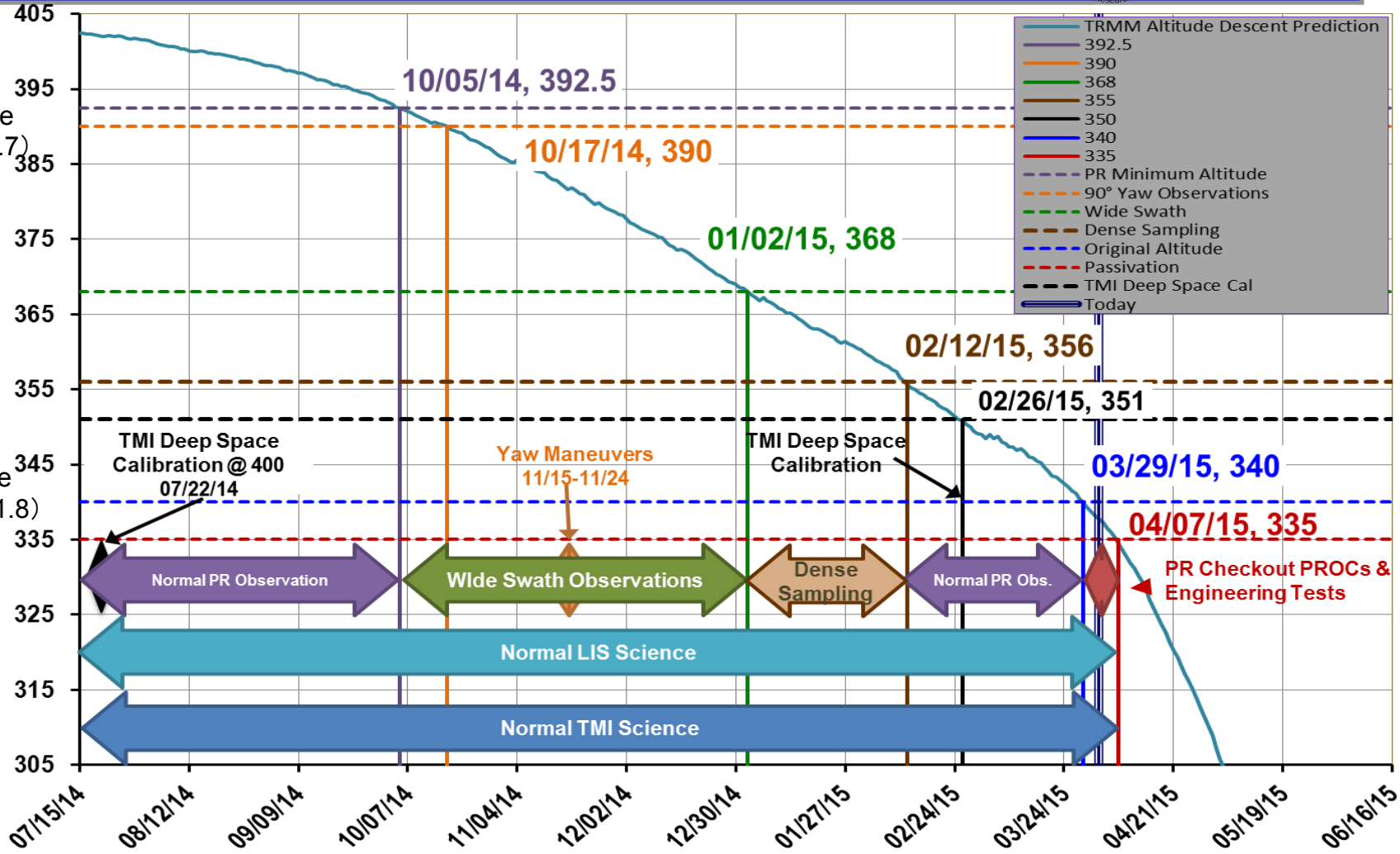
Experimental observation

Note: Altitude and duration of each experimental observation may change due to the satellite operation (e.g. 180 deg. Yaw turn) and the satellite condition.
*: see NASA's slides for GISM on 5 June 2014.

Satellite altitude (from NASA/FOT's presentation)

nominal altitude
(2001.8−2014.7)

nominal altitude
(1997.12−2011.8)



If the solar beta angle is less than 20 degrees, PR's operation was limited only day side of the orbit, because of battery issue.

Summary of the experiments

Table 1. TRMM EOM experiments (summary)

Experiment/events	Duration	Orbit number	SMA satellite altitude range
Normal observation	2014/7/16 – 2014/10/7*	–#93230	–392.0 km
Wide swath #1	2014/10/27–2014/11/15	#96537 – #96832	387.3 km – 382.5 km
90-degree yaw maneuver	2014/11/15–2014/11/25**	#96833 – #96993	382.5 km – 379.8 km
Wide swath #2	2014/11/24–2014/12/17	#96978 – #97333	379.8 km – 373.4 km
Wide swath #3	2014/12/17–2015/1/5	#97334 – #97634	373.4 km – 366.8 km
Dense sampling #1	2015/1/5–2015/1/24	#97635 – #97914	366.8 km – 361.9 km
Dense sampling #2	2015/1/24–2015/2/12	#97915 – #98231	361.9 km – 355.7 km
Normal observation	2015/2/12–	#98231 –	355.7 km – 340.0 km
Instrument checkout	*2015/3/30–*		340.0 km
Passivation of PR			

*: Data are open until 7 October for general users. Normal observation was implemented between 7 and 27 October.

**: 90-deg yaw orbits are listed in Table 2.

Summary of 90 degree yaw (90Y) experiment

Table 2 Orbits for 90-deg yaw experiment

90-degree yaw maneuver	Experimental orbit number	Phase code
Day #1 (2014/11/15)	96834 96835 96836 96837 96838	90-degree yaw maneuver
Day #2 (2014/11/16)	96849 96850 96851 96852 96853	90-degree yaw maneuver
Day #3 (2014/11/17)	96865 96866 96867 96868 96869	90-degree yaw maneuver
Day #4 (2014/11/18)	96880 96881 96882 96883 96884	90-degree yaw maneuver
Day #5 (2014/11/19)	96896 96897 96898 96899 96900	90-degree yaw maneuver
Day #6 (2014/11/20)	96912 96913 96914 96915 96916	90-degree yaw maneuver
Day #7 (2014/11/21)	96927 96928 96929 96930 96931	90-degree yaw maneuver
Day #8 (2014/11/22)	96944 96945 96946 96947	90-degree yaw maneuver
Day #9 (2014/11/23)	96959 96960 96961 96962	90-degree yaw maneuver
Day #10 (2014/11/24)	96975 96976 96977 96878	90-degree yaw maneuver
Day #11 (2014/11/25)	96990 96991 96992 96993	Wide swath #2

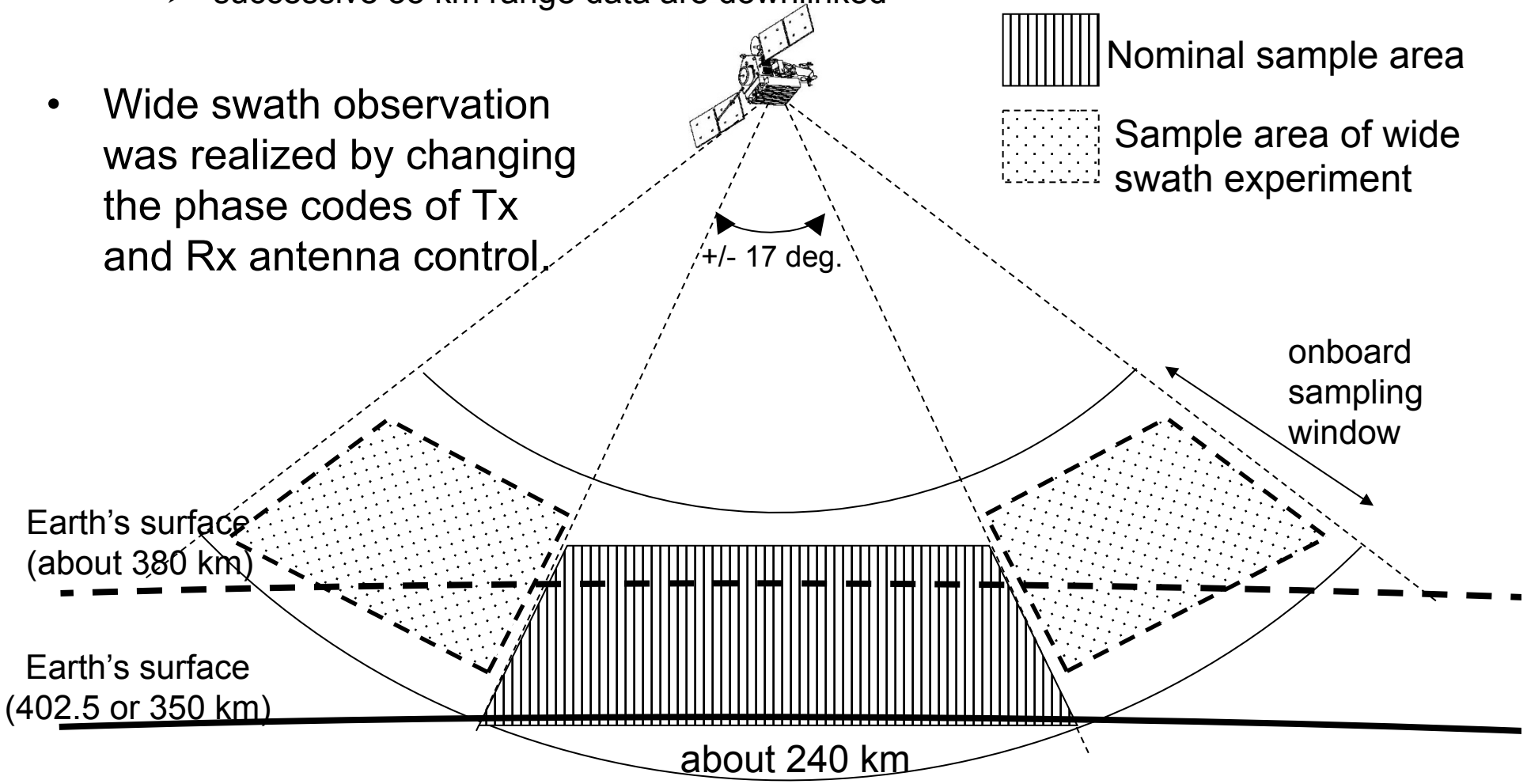
Duration of 90-degree yaw mode was 20 minutes in each orbit and four (4) orbits per day.

TRMM/PR data sampling geometry (cross track)

TRMM/PR data sampling:

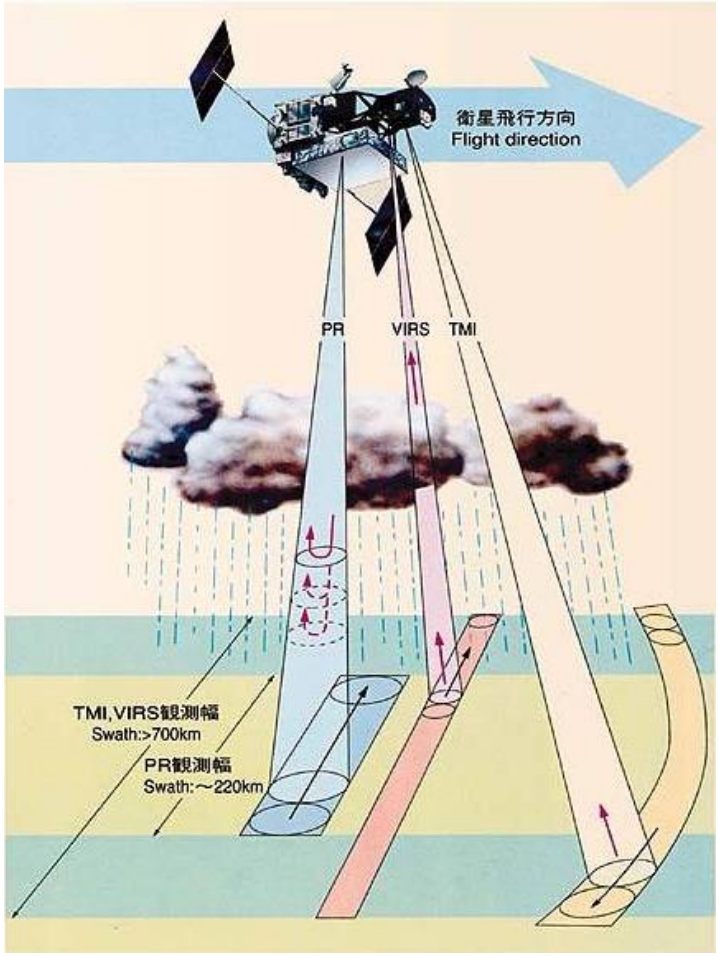
- 49 angle bins for one scan
- fixed onboard sampling range (50 km window)
- successive 35 km range data are downlinked

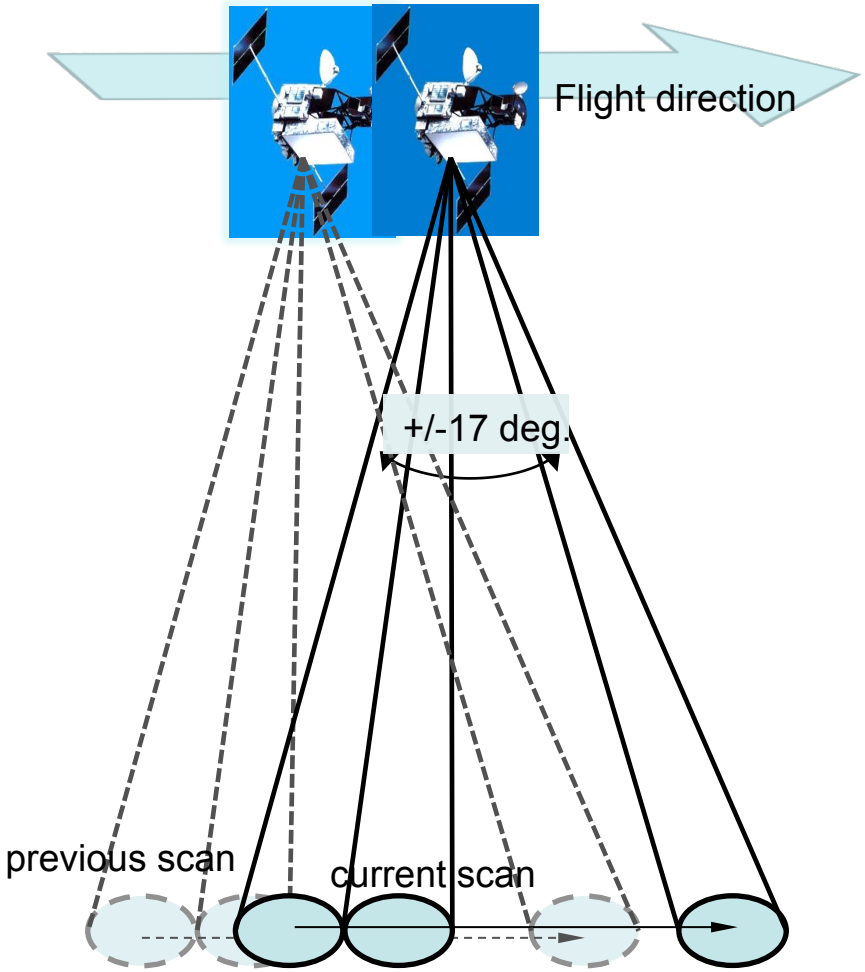
- Wide swath observation was realized by changing the phase codes of Tx and Rx antenna control.



90 deg. yaw observation (schematic image)

Nominal observation → 90 deg. yaw

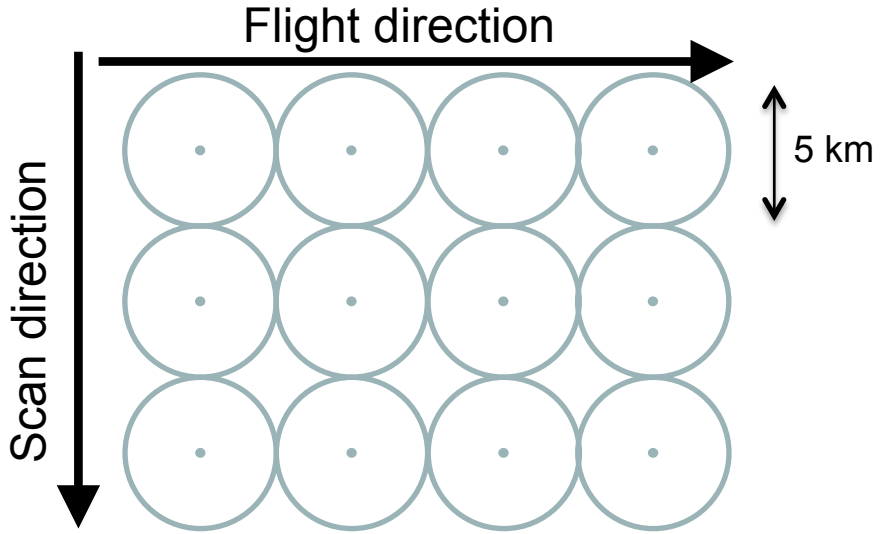




This mode can obtain the rain structure with various incident angles.
TMI will also observe similar data.

2b Dense sampling experiment (external cal. mode)

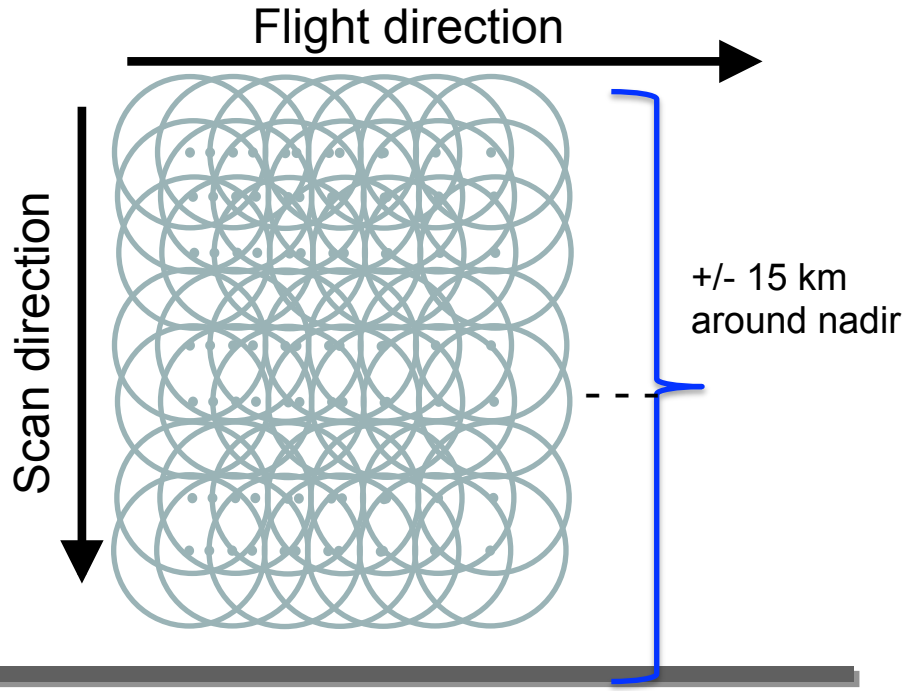
Nominal observation



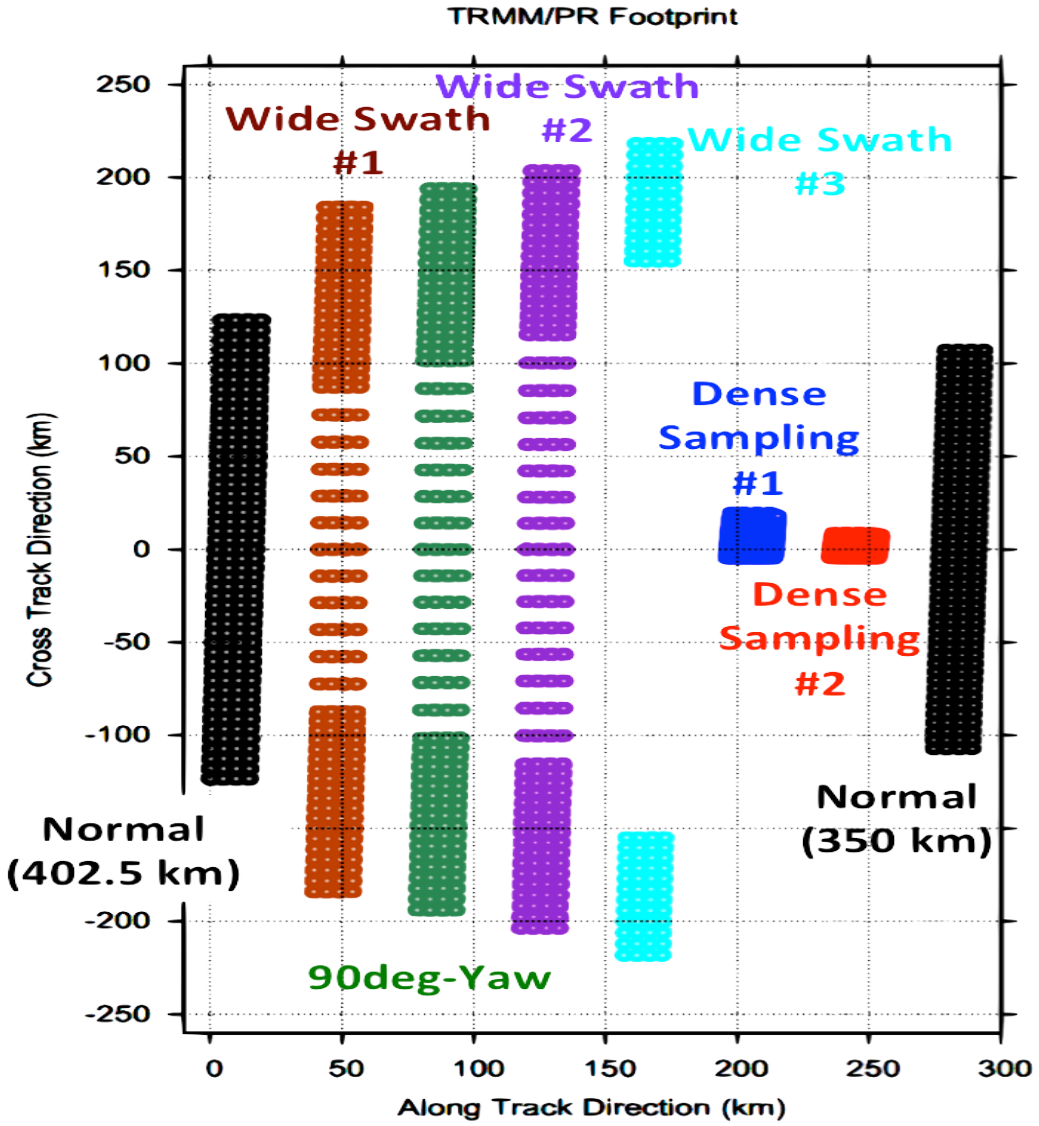
Dense sampling observation

3/4 times dense for scan and flight direction

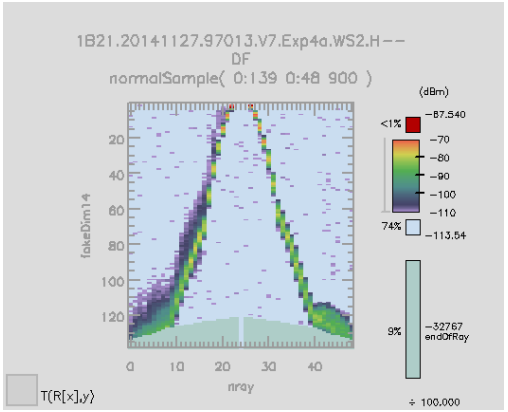
- This experiment was planned to implement external calibration mode.
- Actual experiment was done similar to the wide swath observation but the footprints are concentrated near nadir.

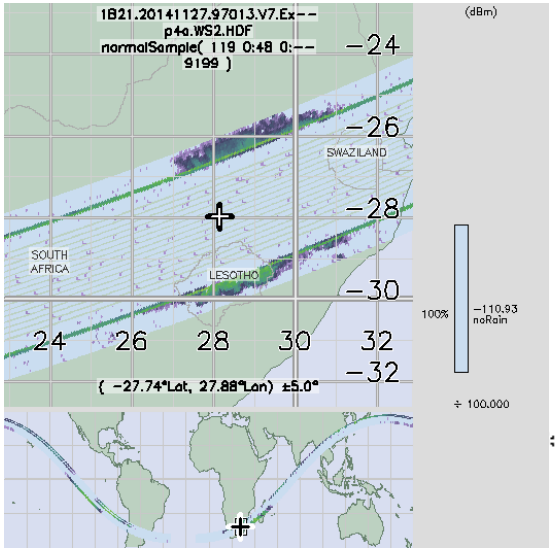


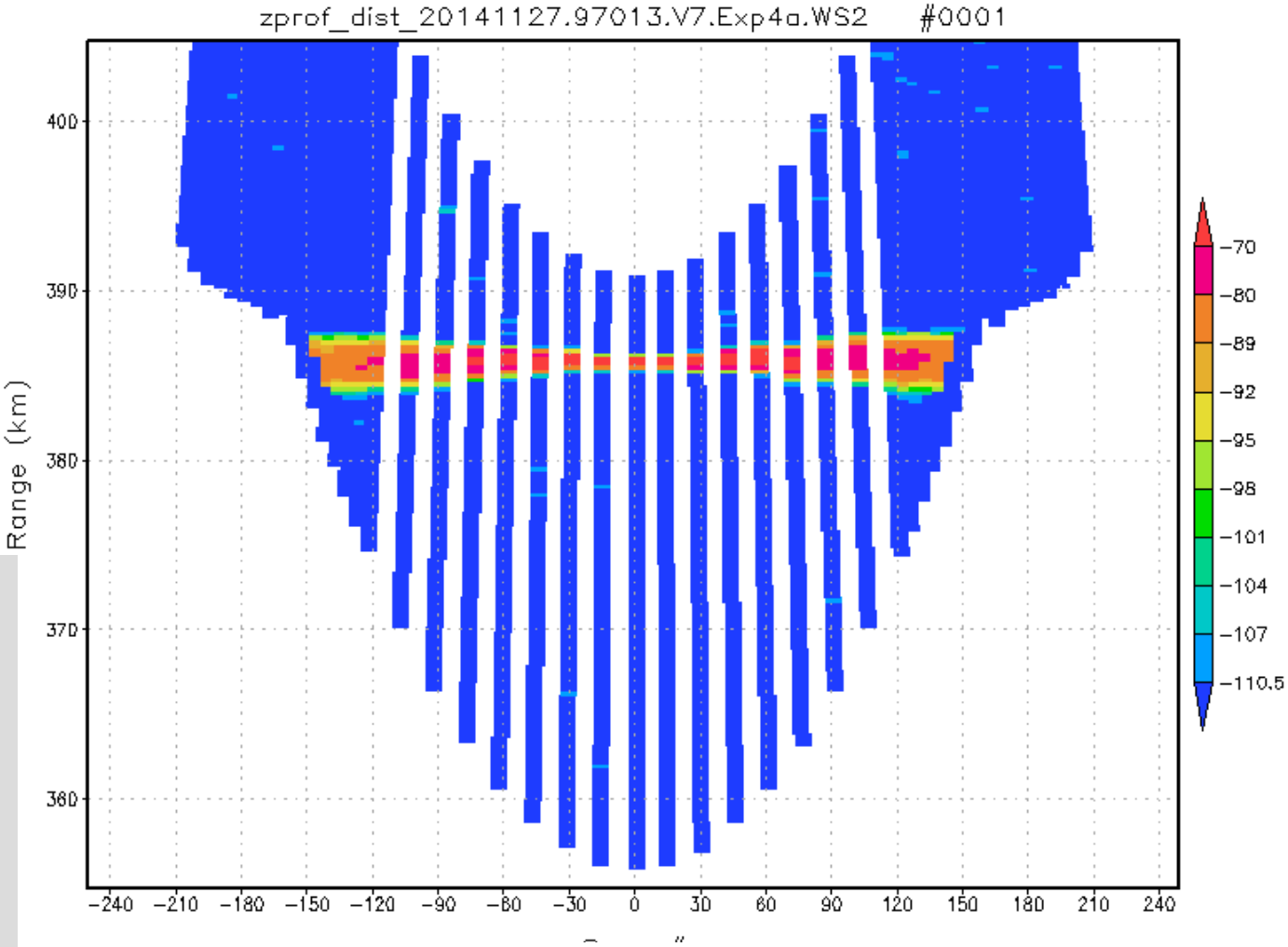
swath settings



Wide swath -2 (swath width: about 420 km)

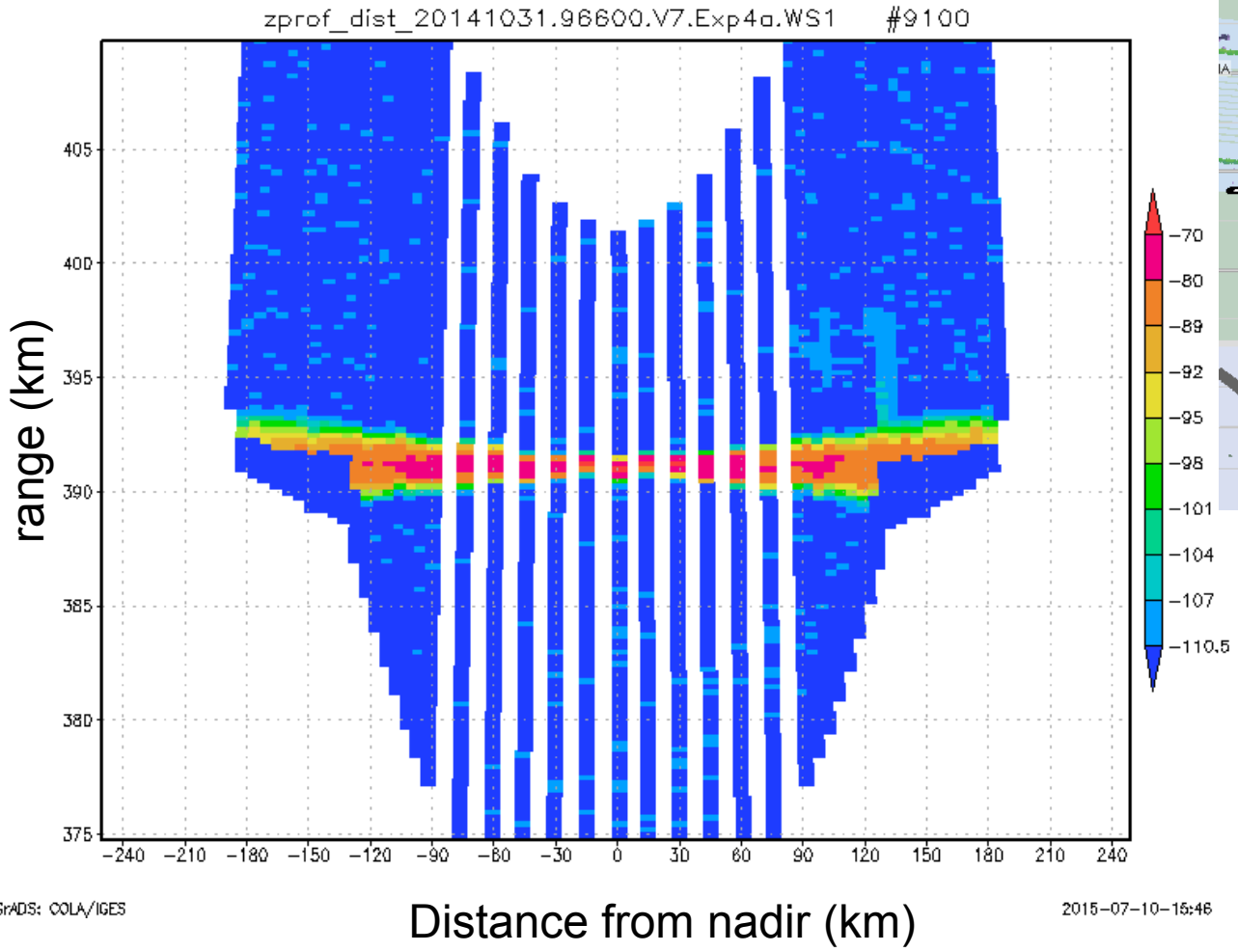


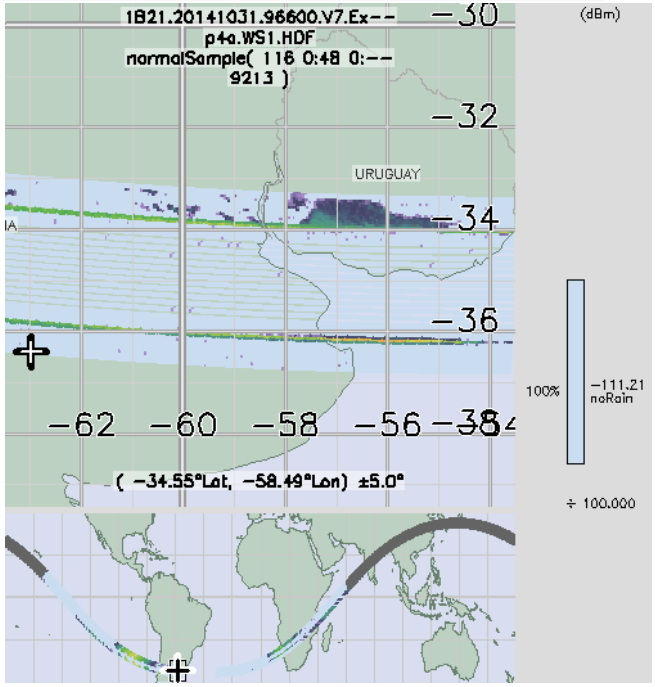


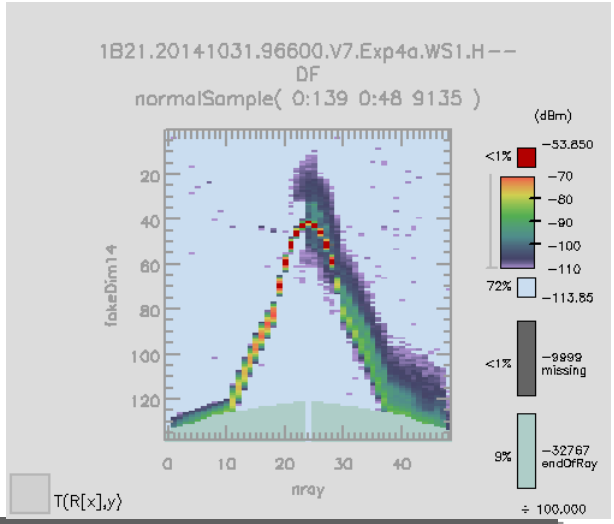


Distance from nadir (km)

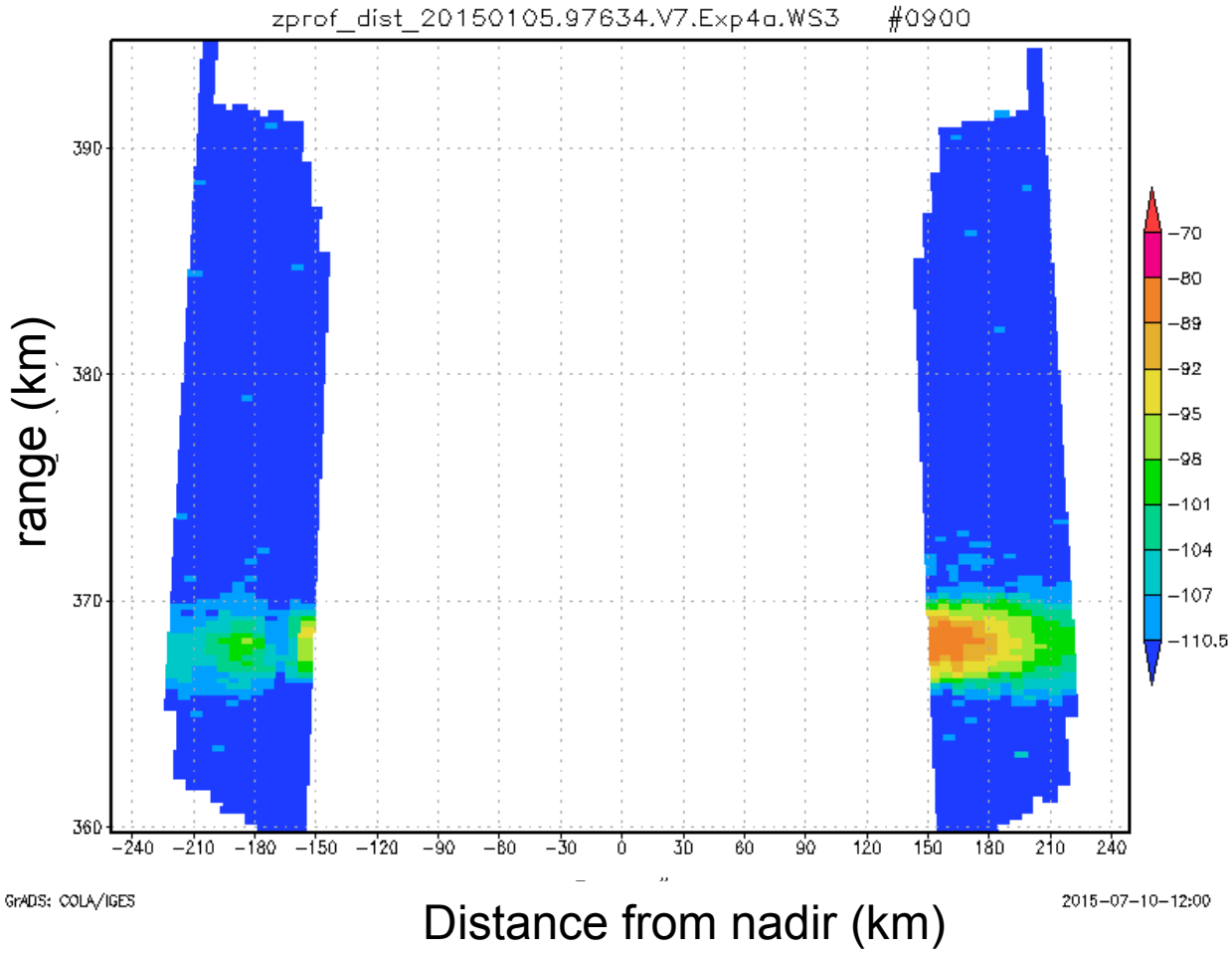
Wide swath -1 (swath width about 360 km)

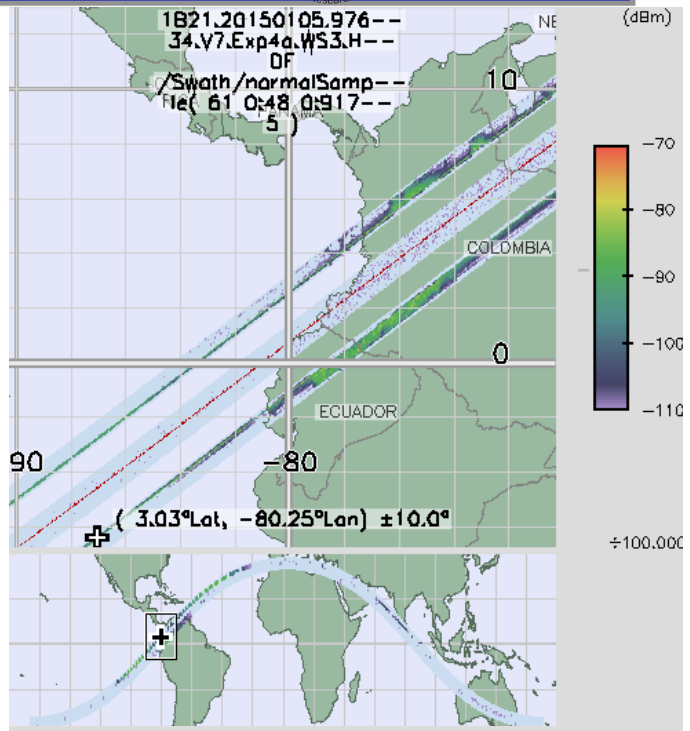


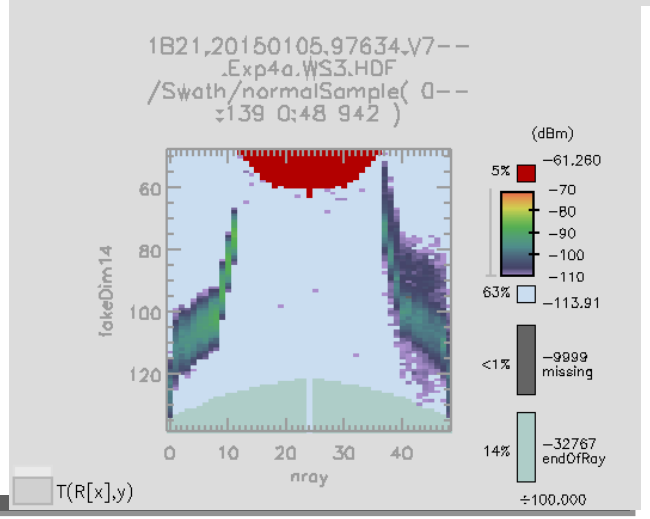




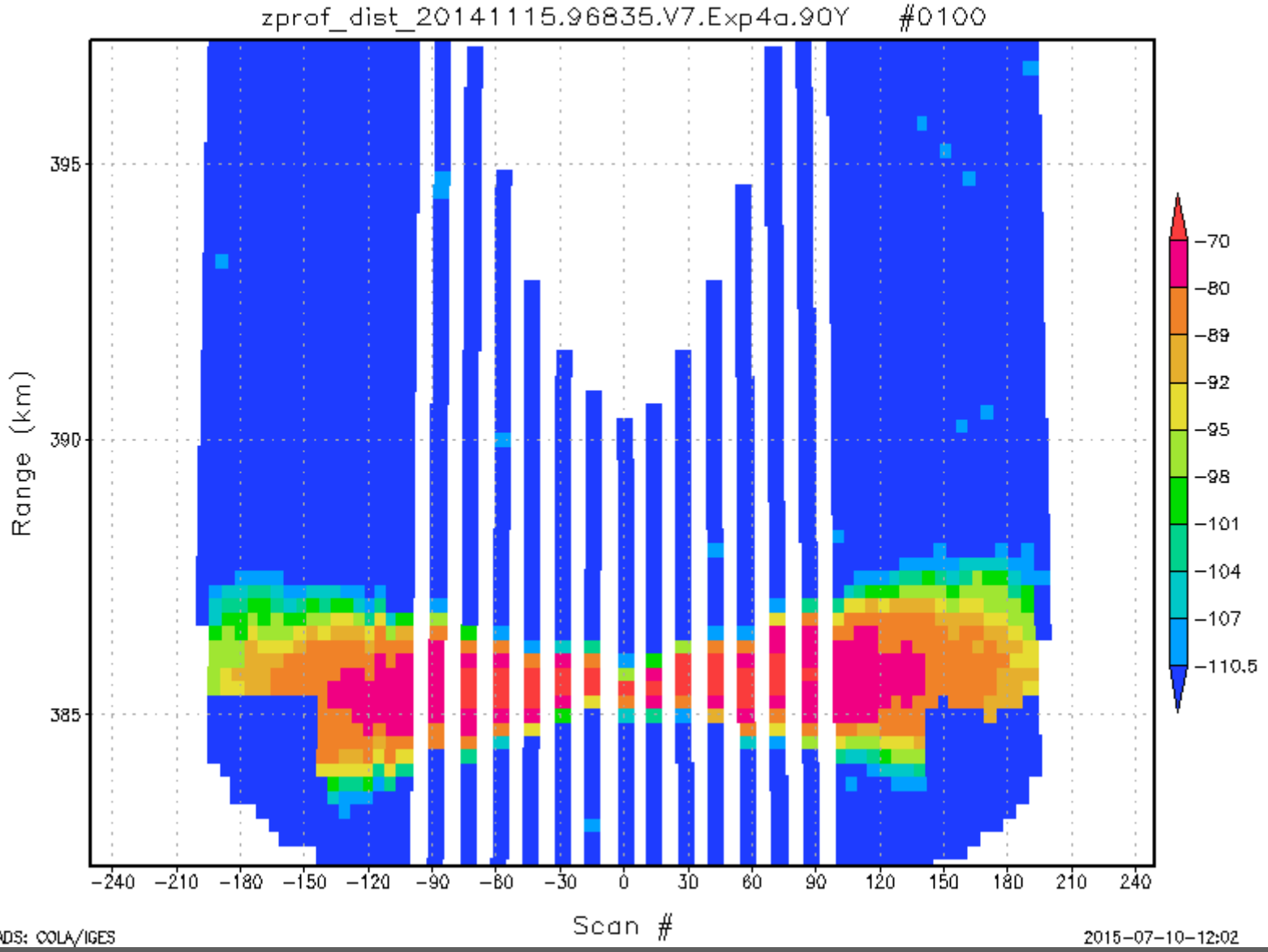
Wide swath-3 (scan edge distance = about 450km)



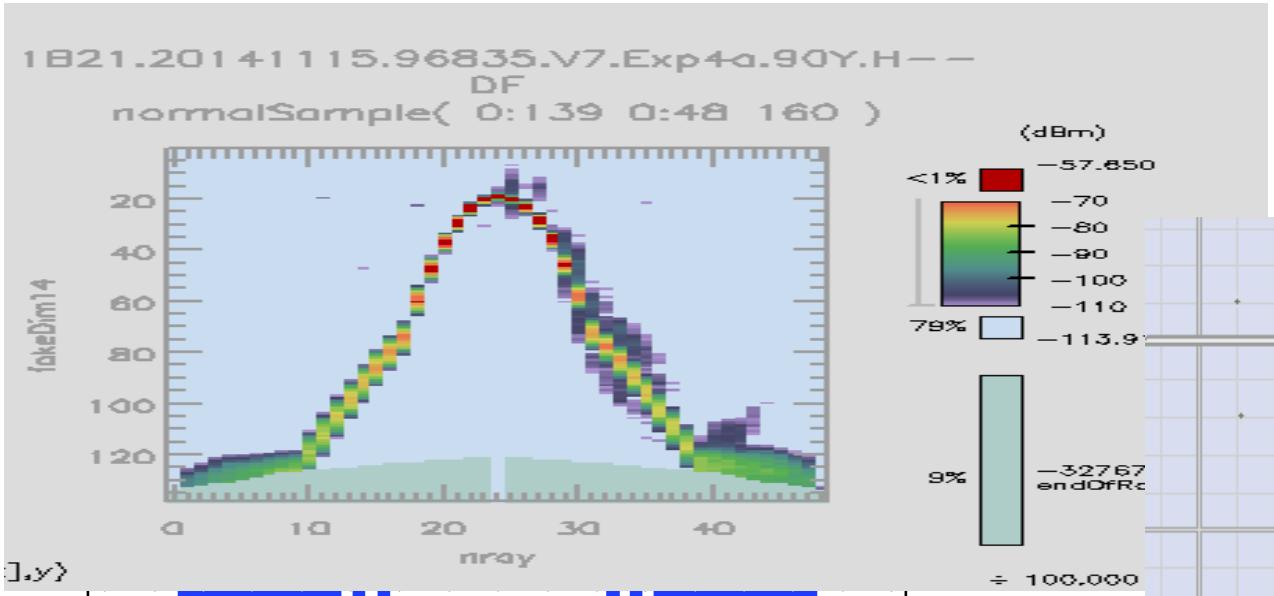


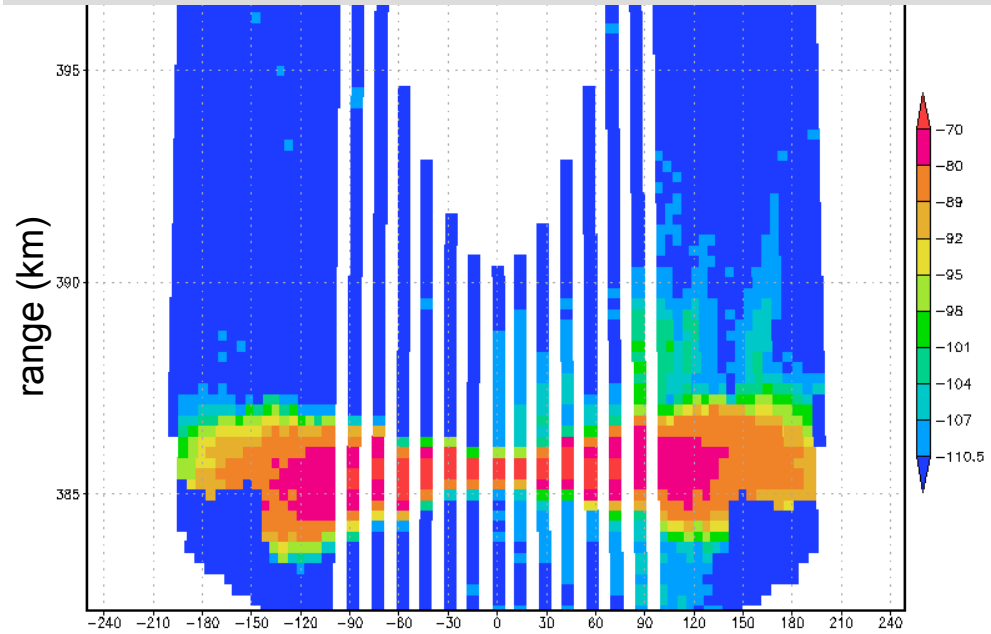


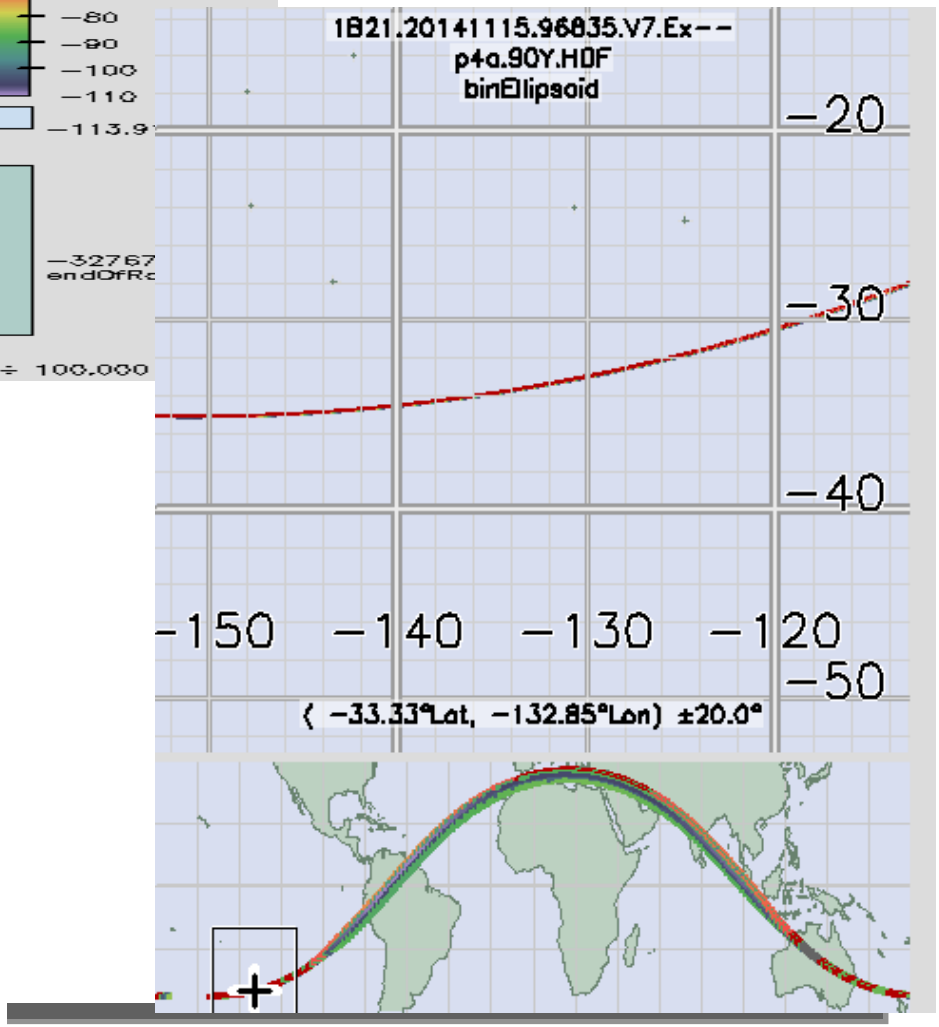
90-degree Yaw examples



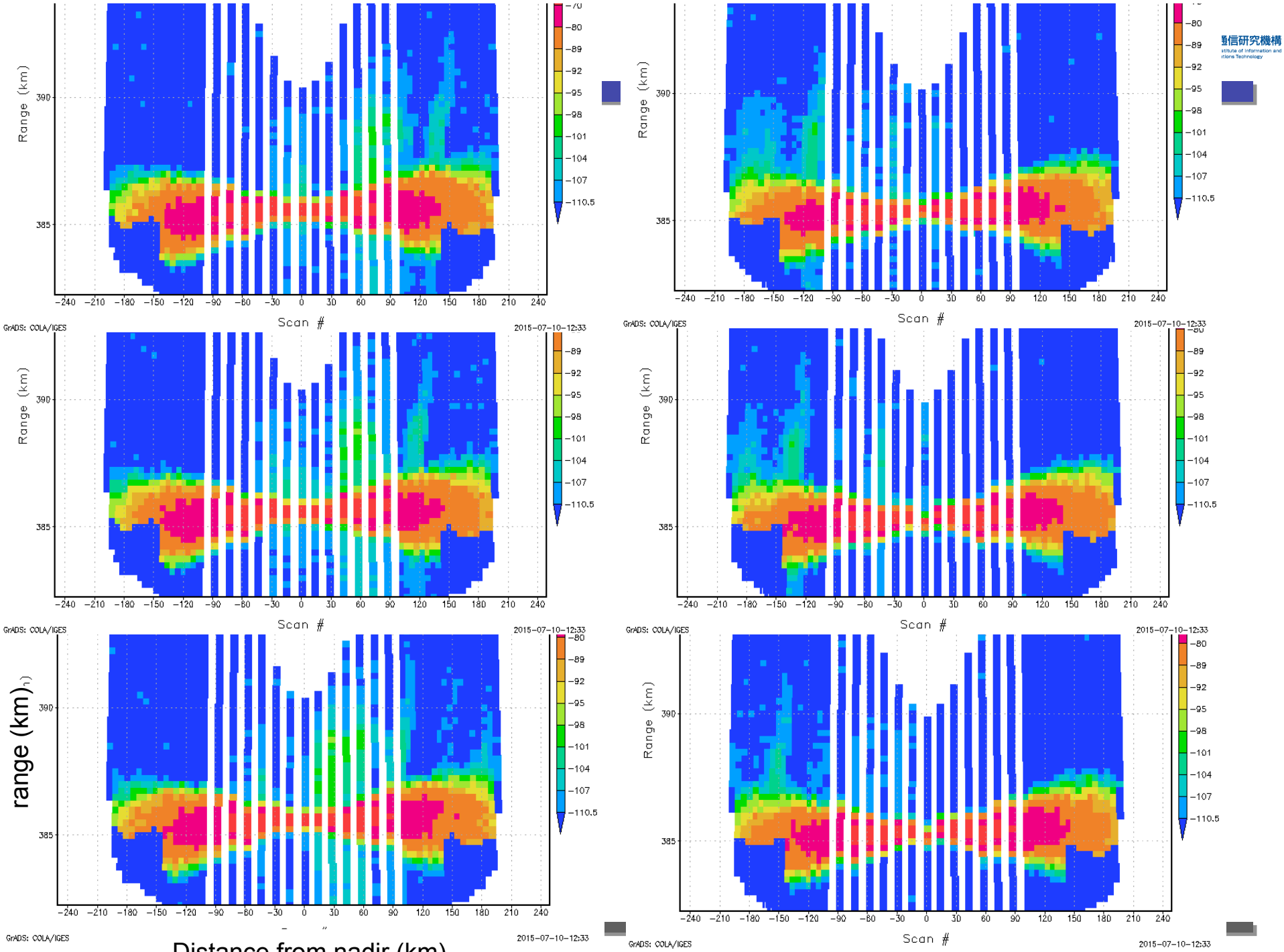
90-degree yaw experiment (frame by frame)







Distance from nadir (km)

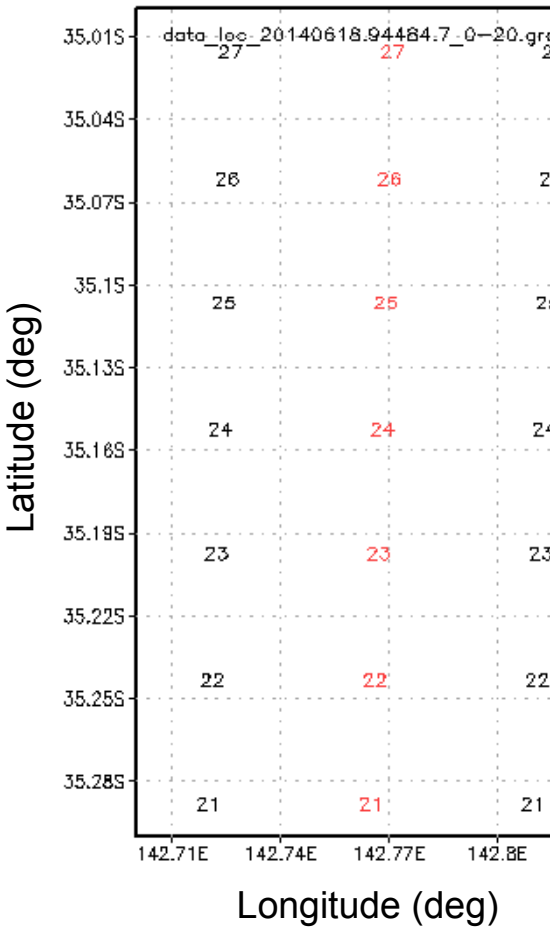

Range (km)
Scan #
GrADS: COLA/IGES
2015-07-10-12:33
range (km)
Distance from nadir (km)

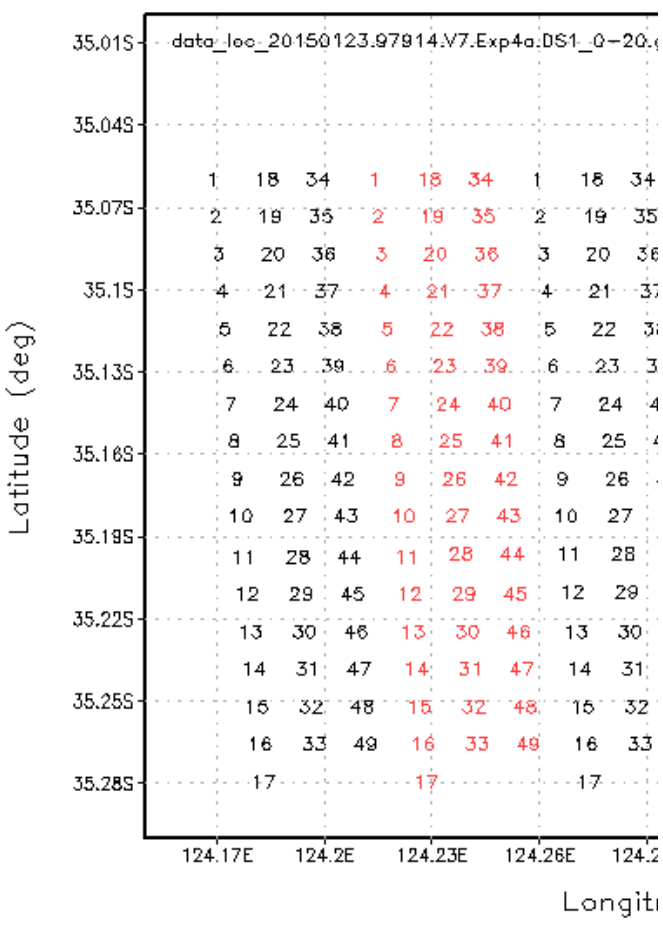
Dense sampling (DS1= 1/3, DS4:1/4)

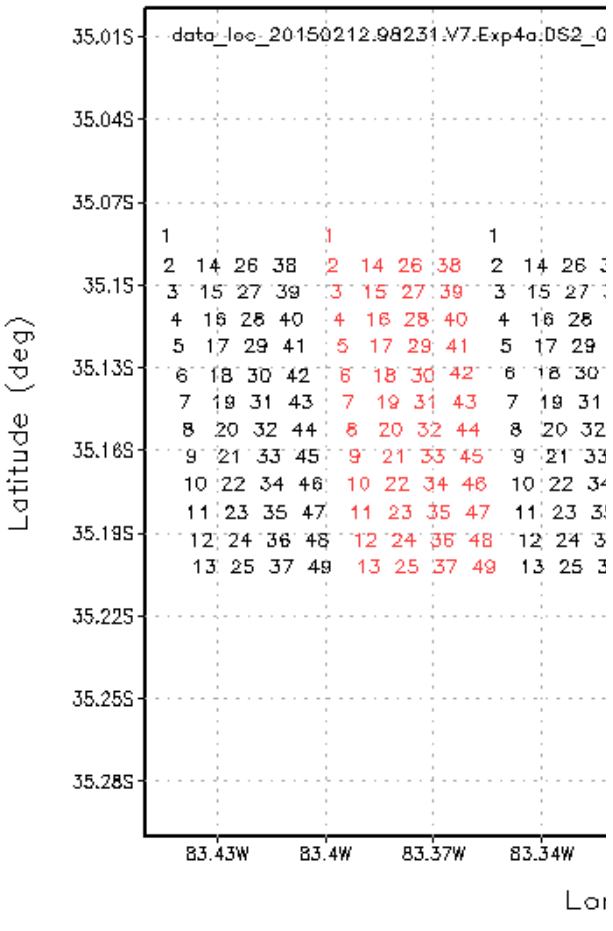
Normal

Dense (1/3)

Dense (1/4)



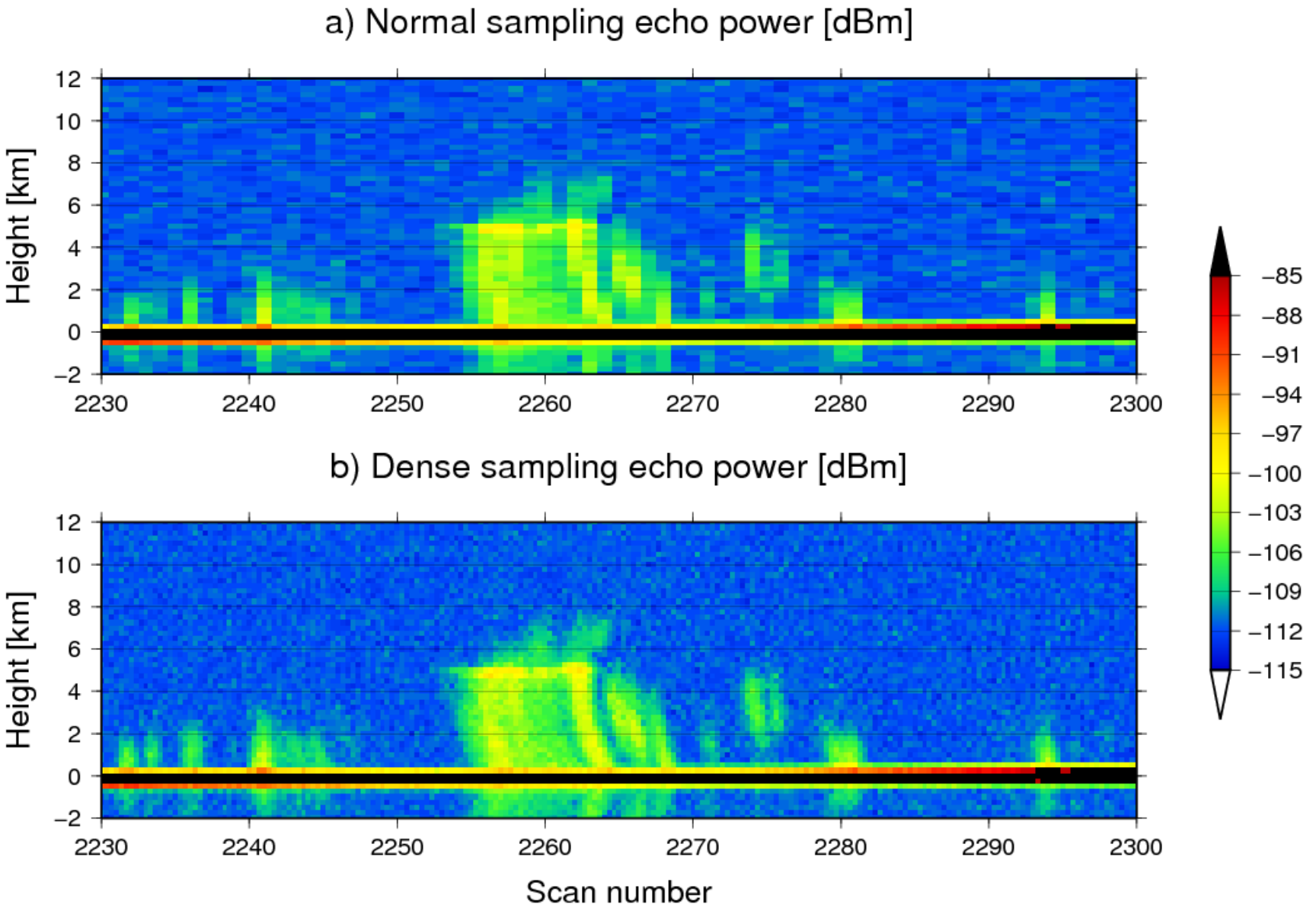




GrADS: COLA/IGES

GrADS: COLA/IGES

Dense sampling experiment



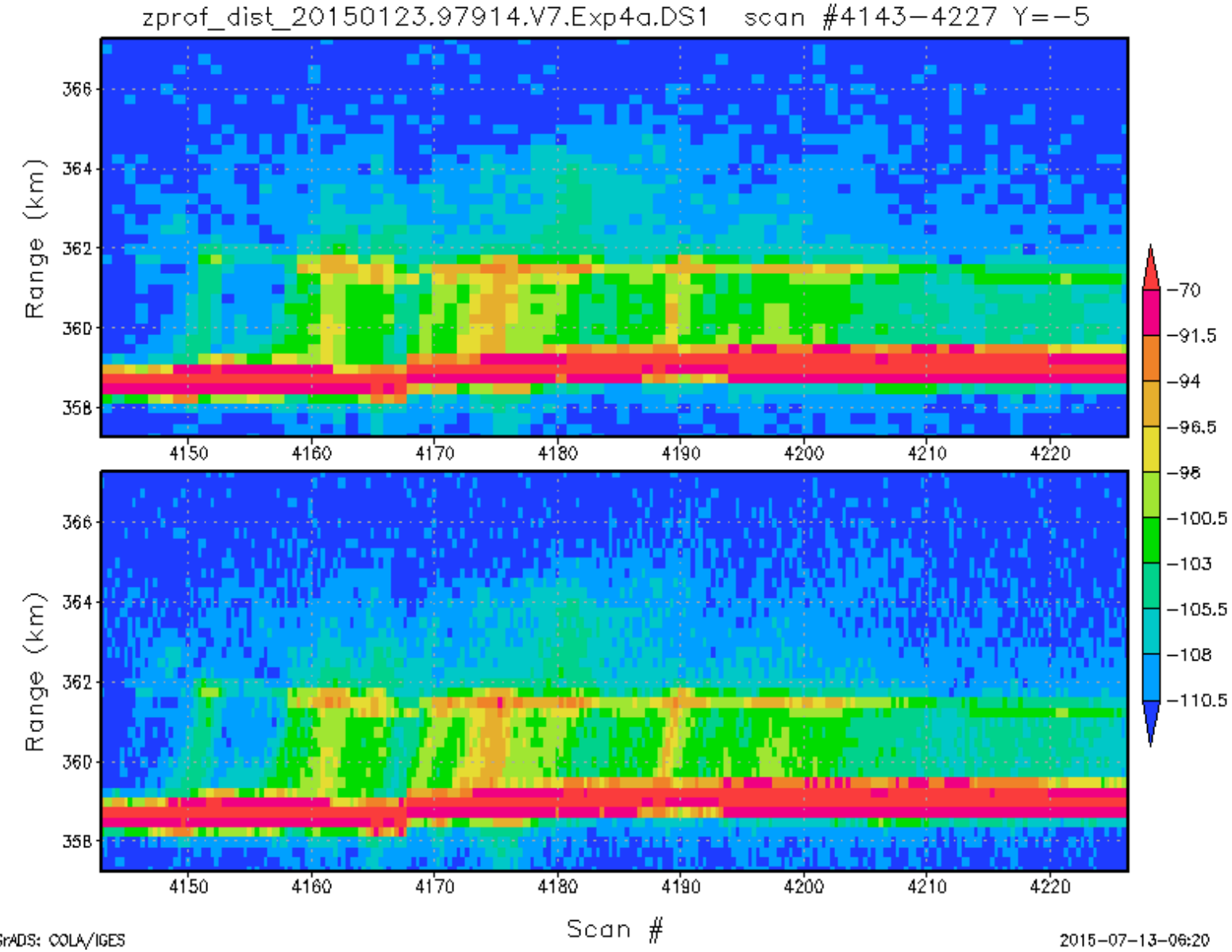
Future works

- Data check
  - Level 1 data
    - geolocation, oversample data, systemNoise, binSurfPeak, etc.
    - satellite attitude (roll and pitch)
  - Level 2 data
    - rain profile, PIA, epsilon
- Analytical works
  - Evaluation of rain profiling algorithm by using 90Y data.
    - compare the rain profiles of various incident angles.
  - Dense sampling data analysis to seek the possibility to retrieve the fine structure of the precipitation.
  - Studies on the wider swath operation of future precipitation radar by using the wide swath experimental data.

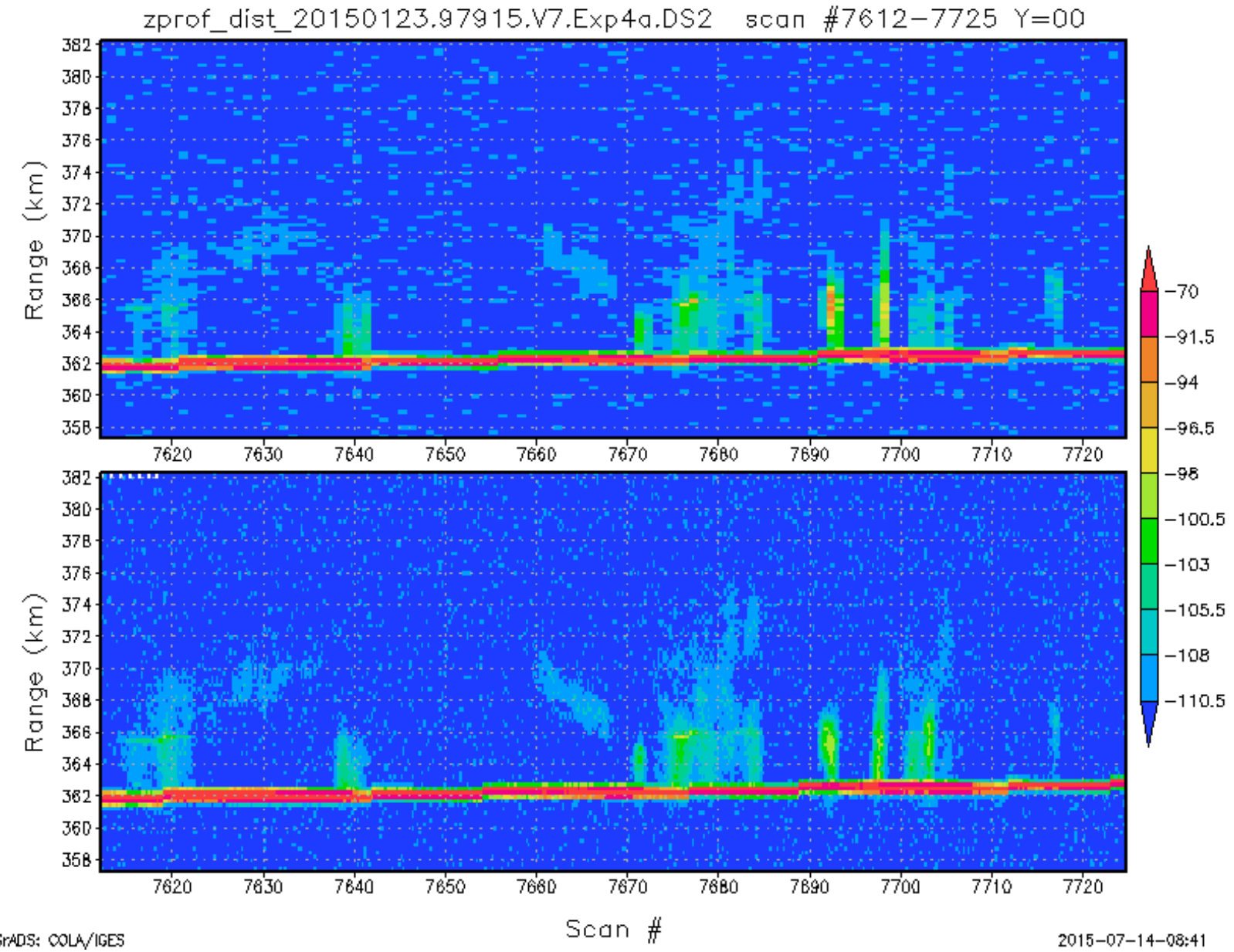
Acknowledgements

- I would like to express my sincere appreciation to
  - TRMM Flight Operation Team (FOT) of NASA for the implementation of these experiments.
  - JAXA/MOSS and RESTEC TRMM team members for the data processing and algorithms modification.

Dense sampling experiment 1(along track cross section)

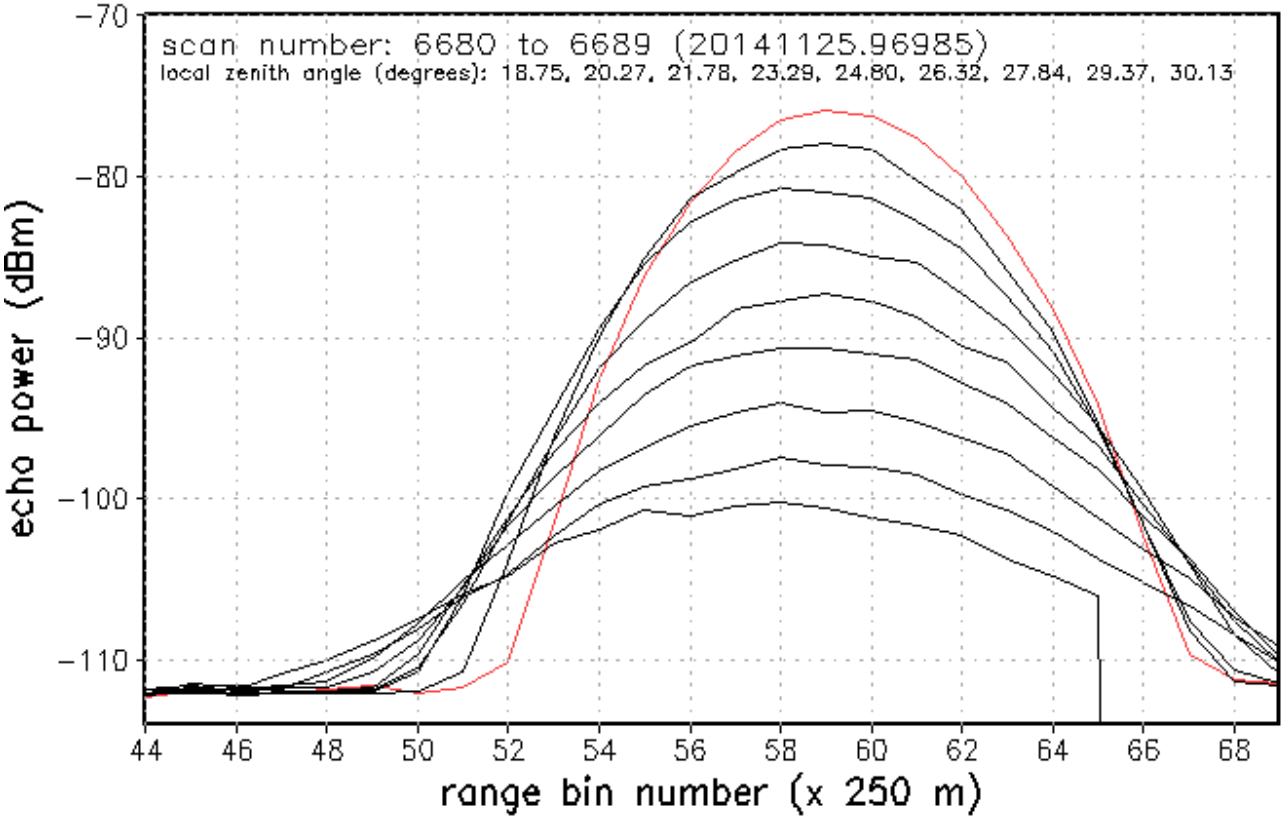


Dense sampling experiment 2 (along track cross section)

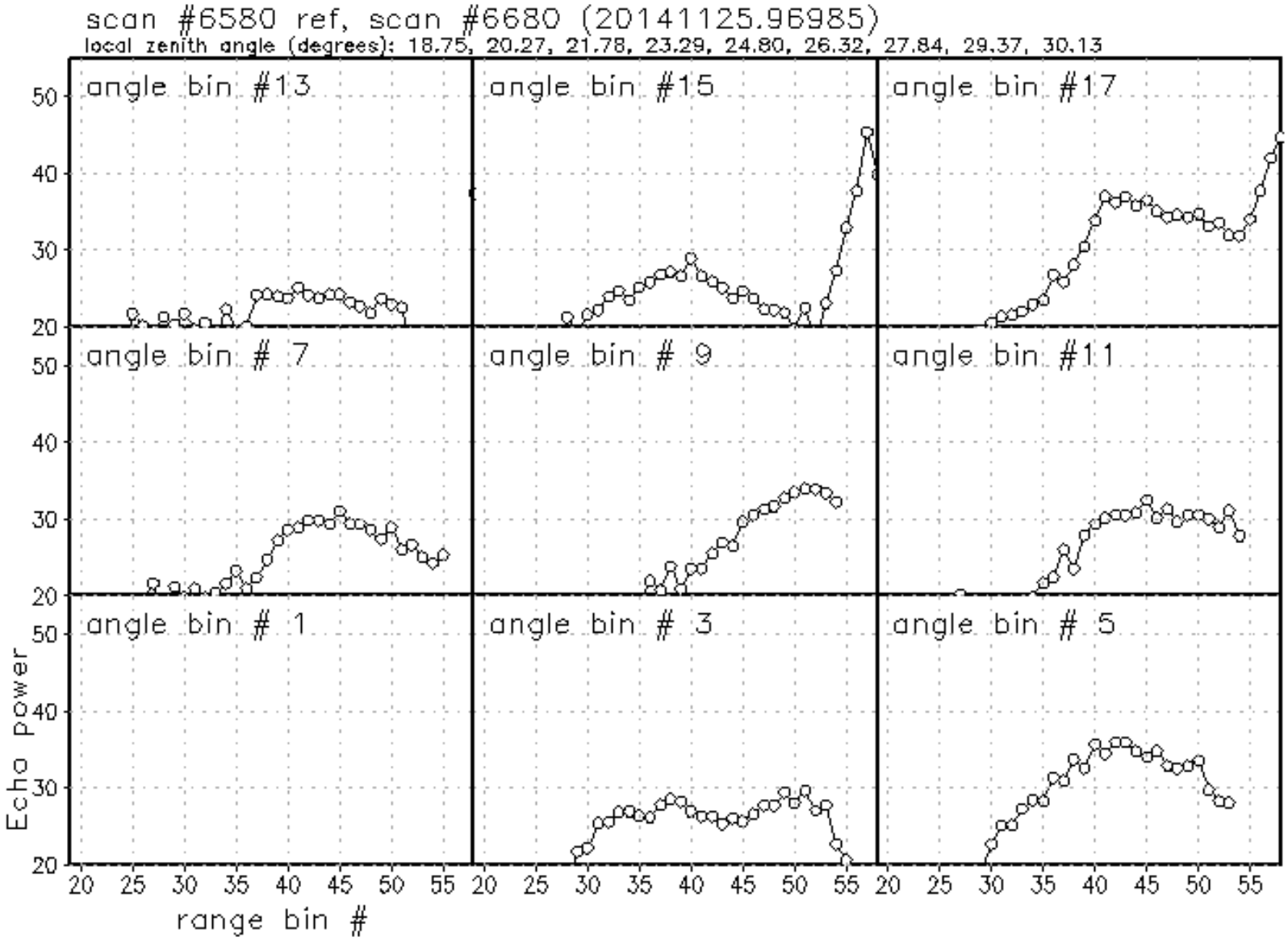


Surface echo profile (WS1)

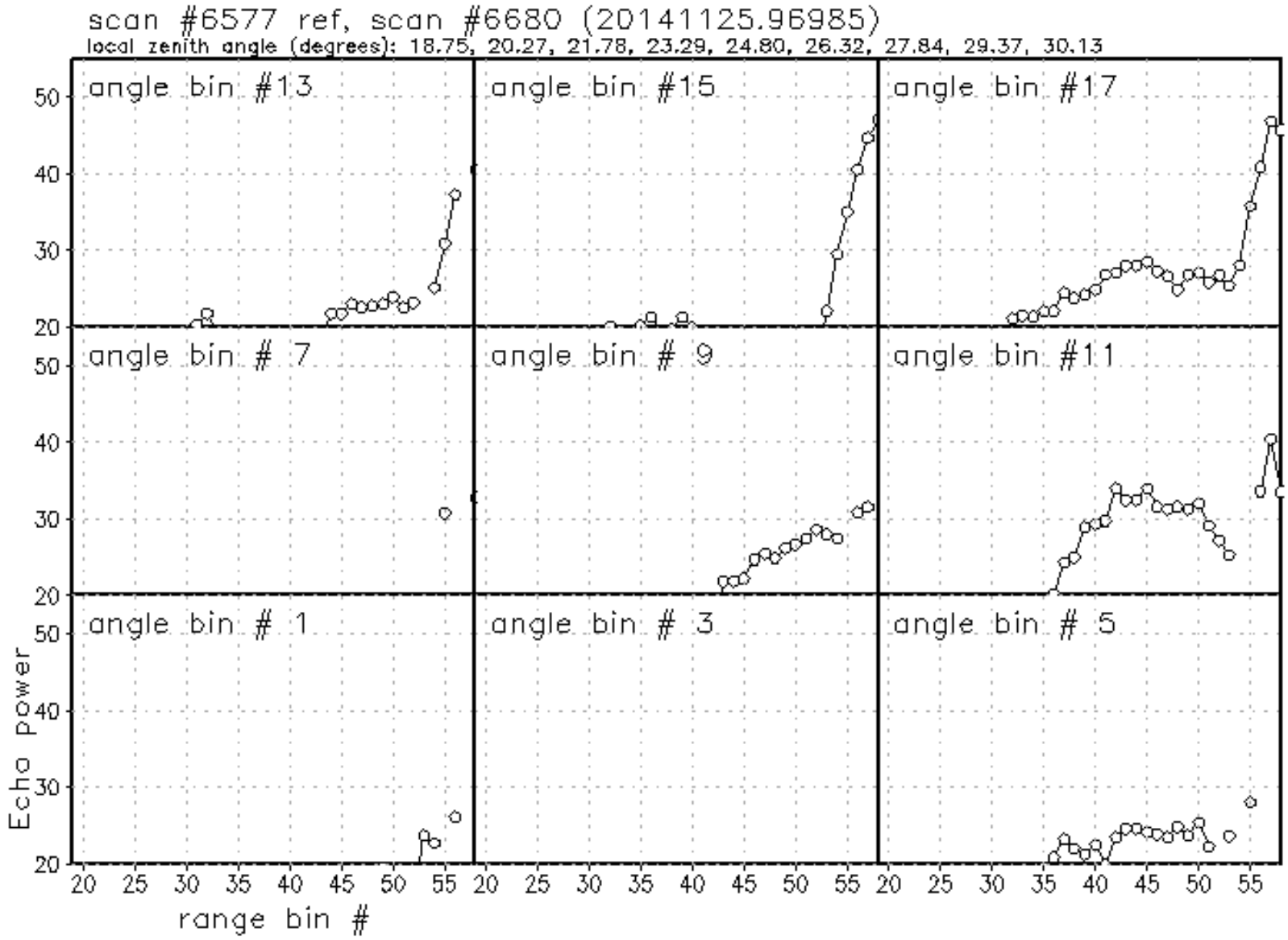
Averaged surface echo profile.
Red line corresponds to the scan edge profile of normal observation.
→clutter peak of 30 deg incident angle is more than 20 dB smaller than that of 18 deg incident angle.　Several dB higher than the noise level.
→wide swath data can be usable for moderate to heavy rainfall.



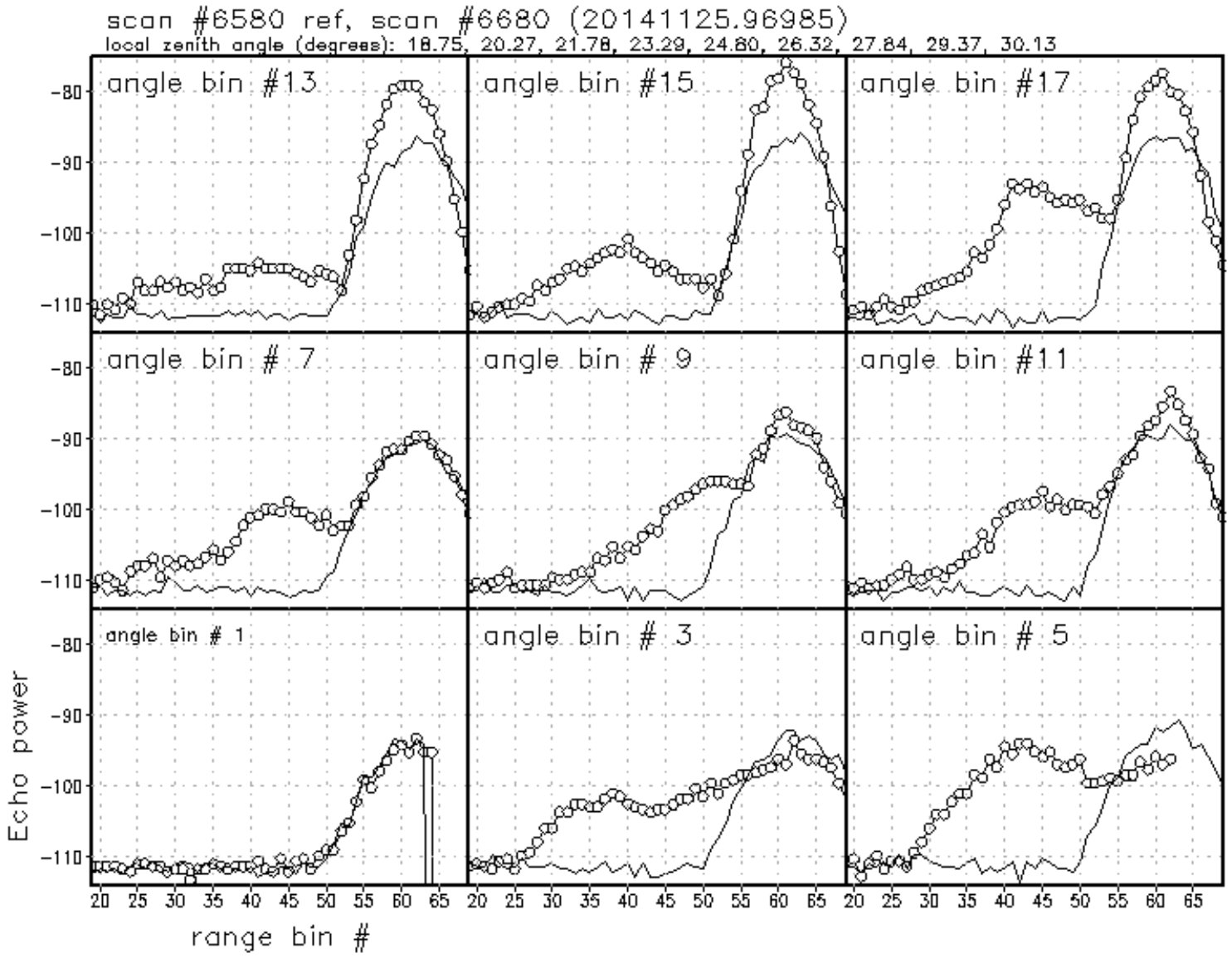
echo profile comparison (rain vs no-rain)



echo profile comparison (rain vs no-rain)



echo profile comparison (rain vs no-rain)



L1B21 product check

- parameters modified for special experiment:
  - geolocation (latitude, longitude), binEllipsoid, scLocalZenith
- parameters not modified for special experiment:
  - systemNoise, rain/no-rain flag, binSurfPeak, osBinStart, etc.
  - some parameters are not reliable.
- satellite attitude is also needed to be checked.

Data processing

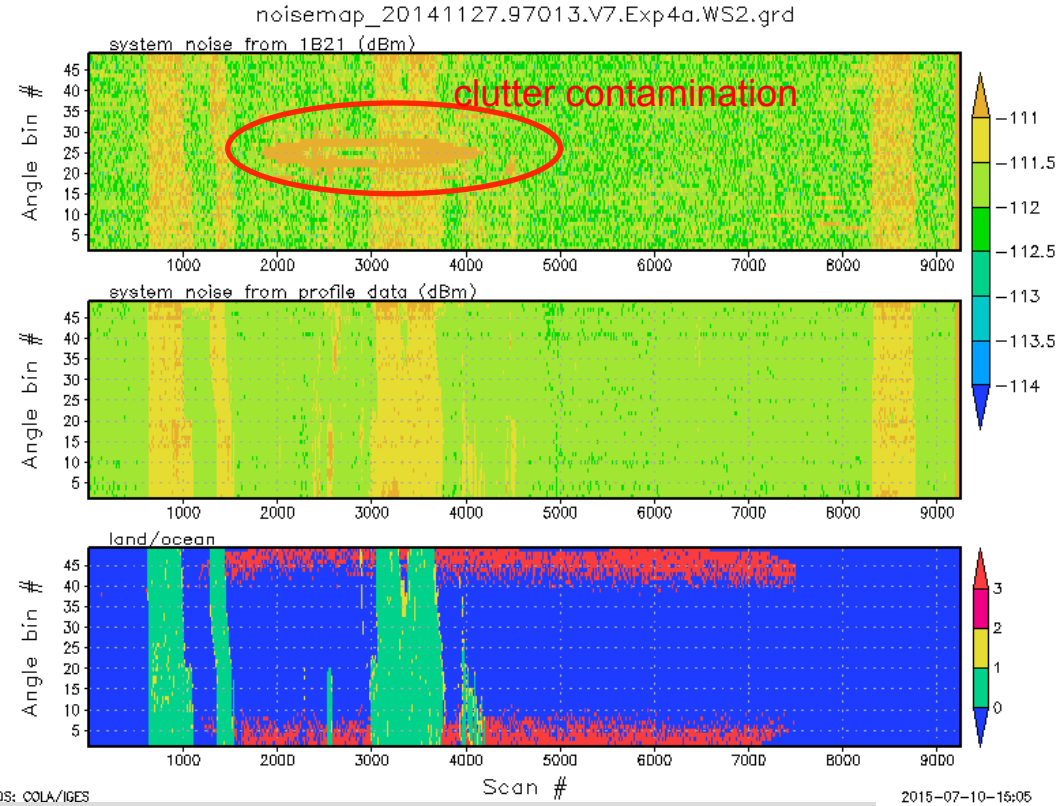
	Level 1	Level 2
normal obs. mode	Yes	Yes*
Wide swath	Yes**	No
90 deg Yaw	Yes**	No
Dense sampling	Yes	No*

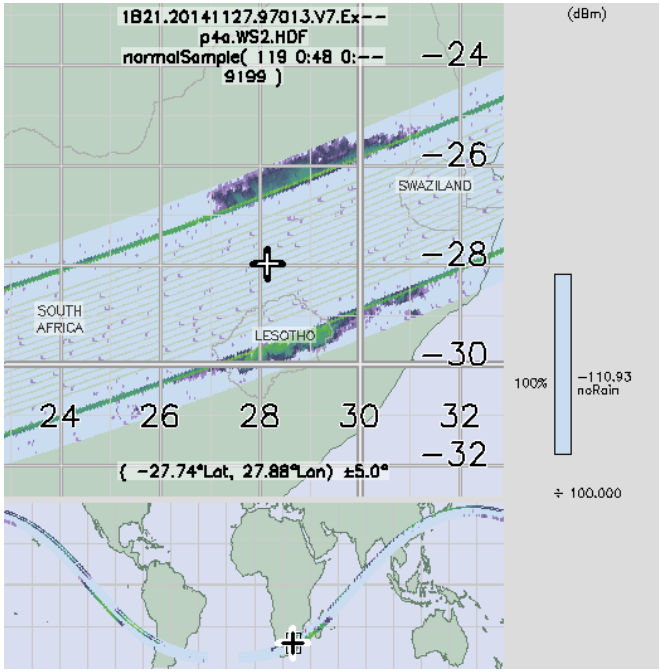
*: Quantities of estimated rain profile must be evaluated.
rain top height information may not be valid.

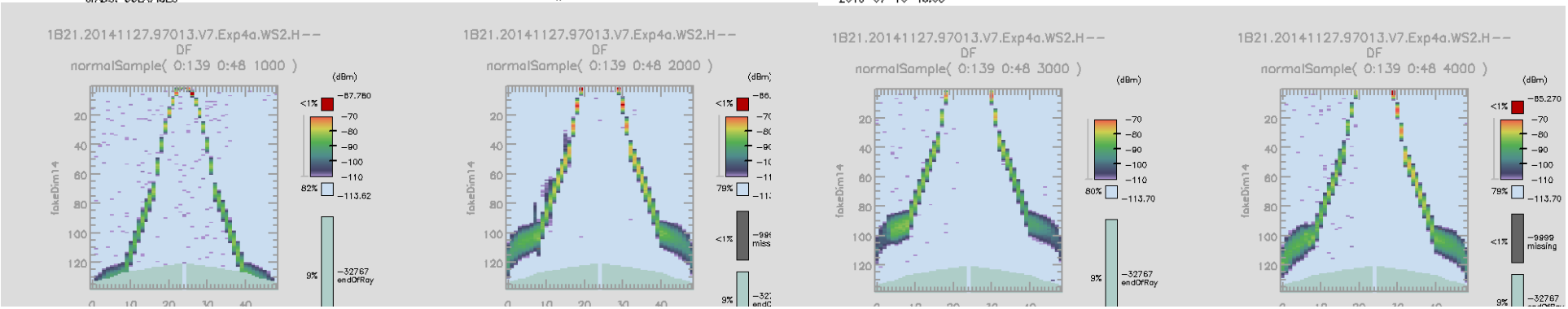
** : Over-sampling data are no longer useful.
binSurfPeak, systemNoise, rain flag, etc are not reliable.
Because of above reasons, Level 2 processing was not implemented.

System noise evaluation

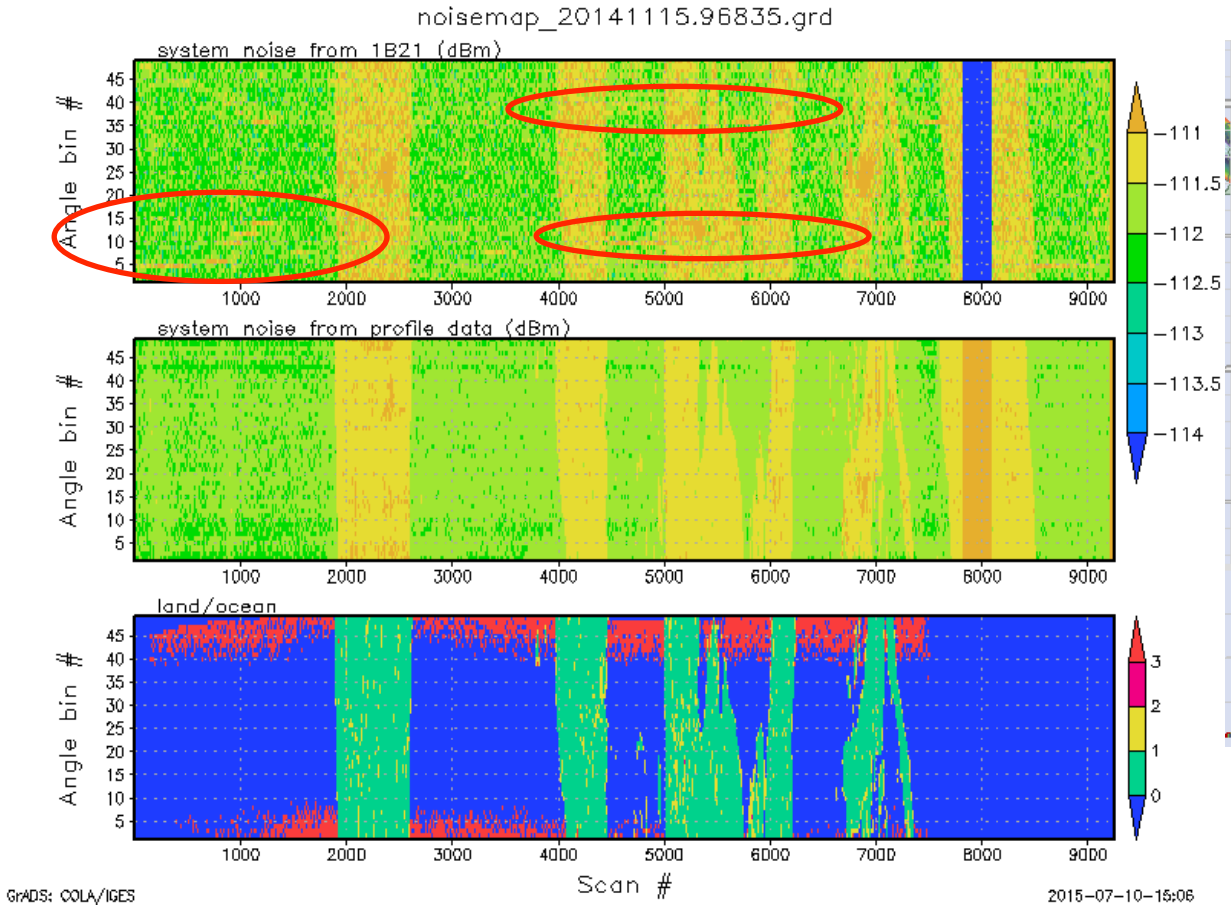
comparison between normal noise sample data (top) and no-rain echo average (middle)

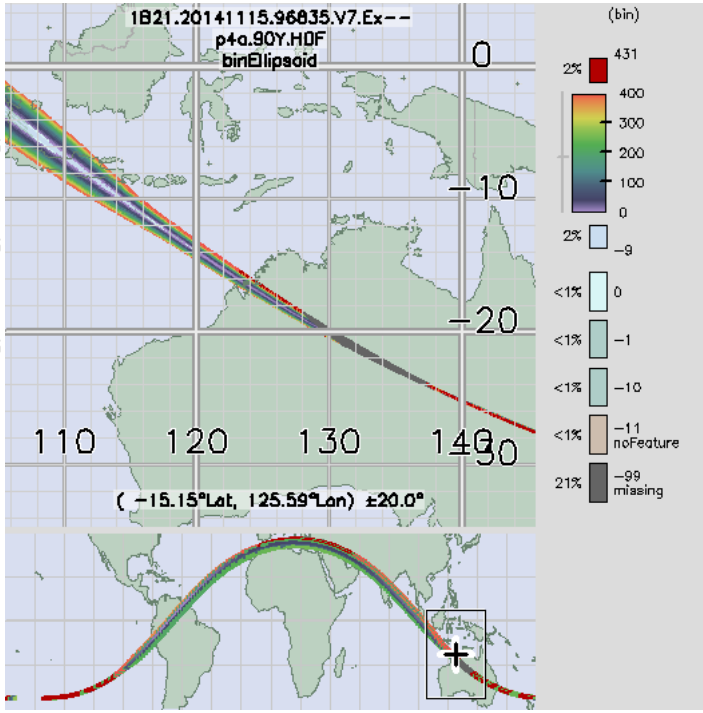




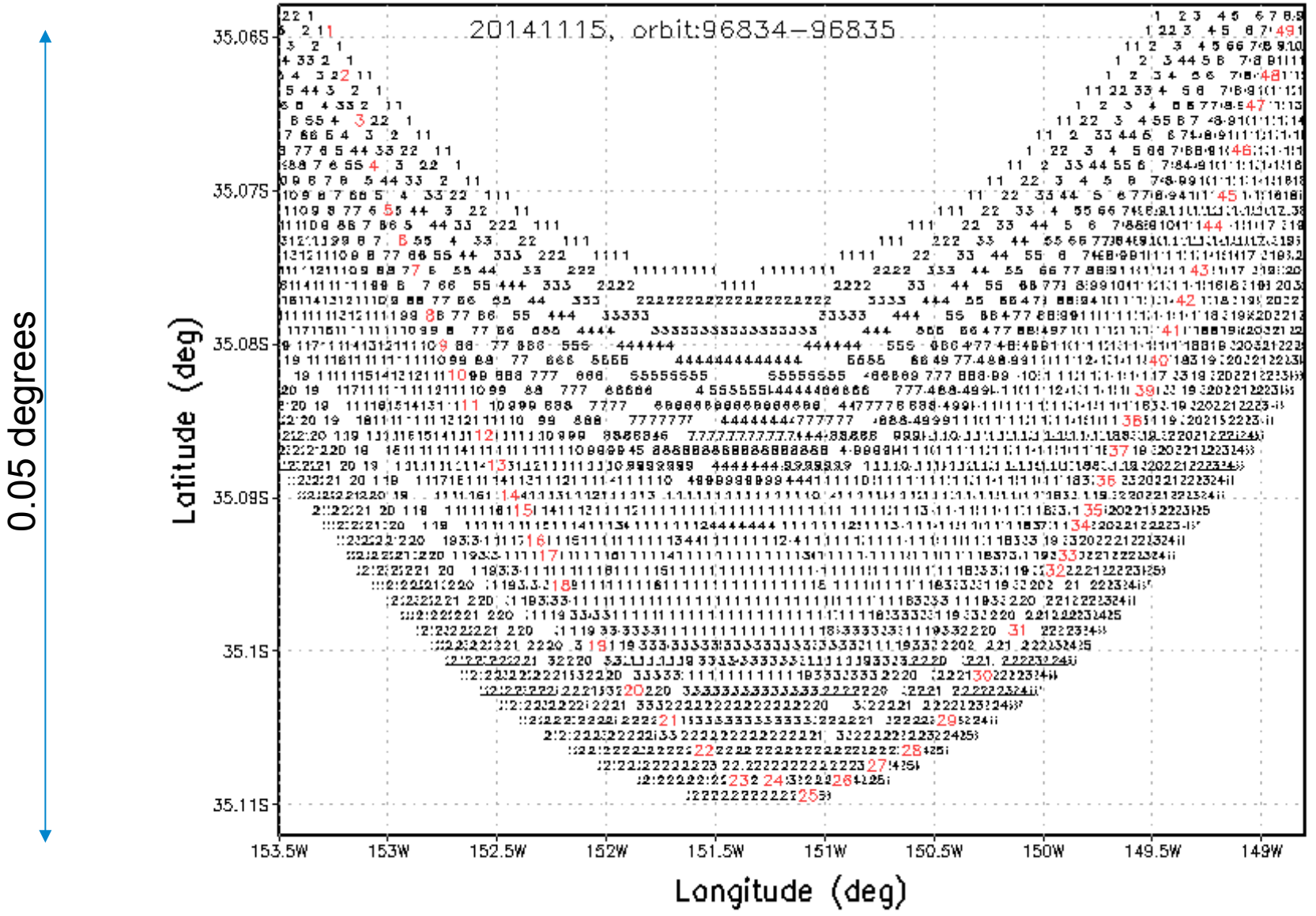


System noise evaluation (90Y case)

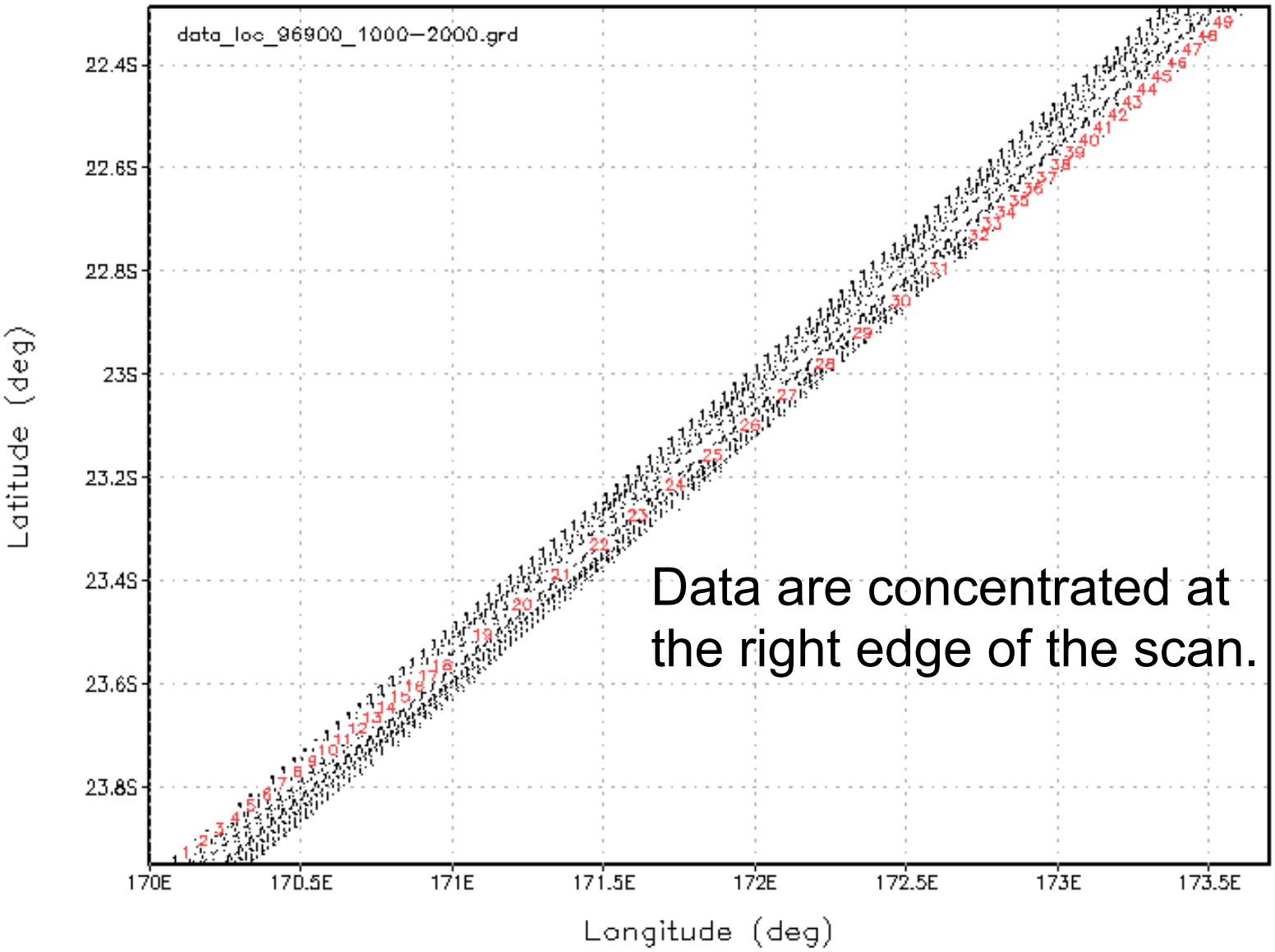




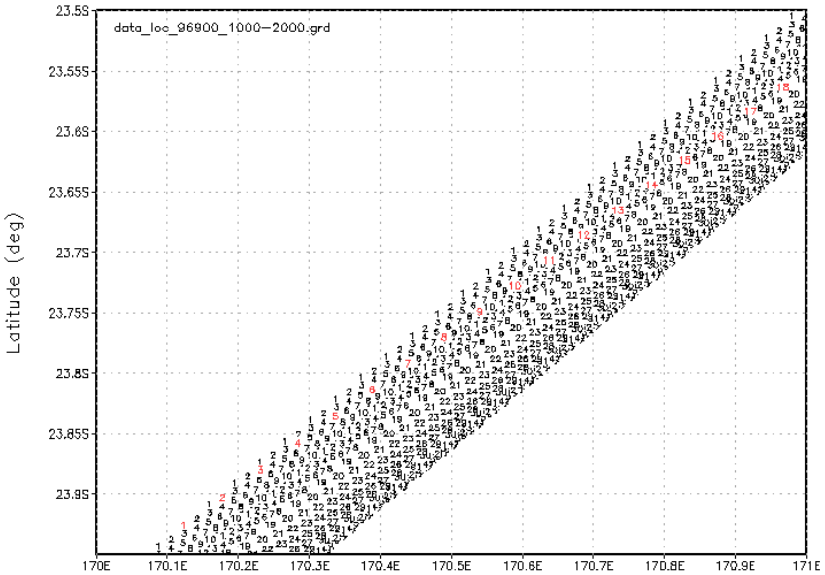
footprint trajectory (90Y） @35S

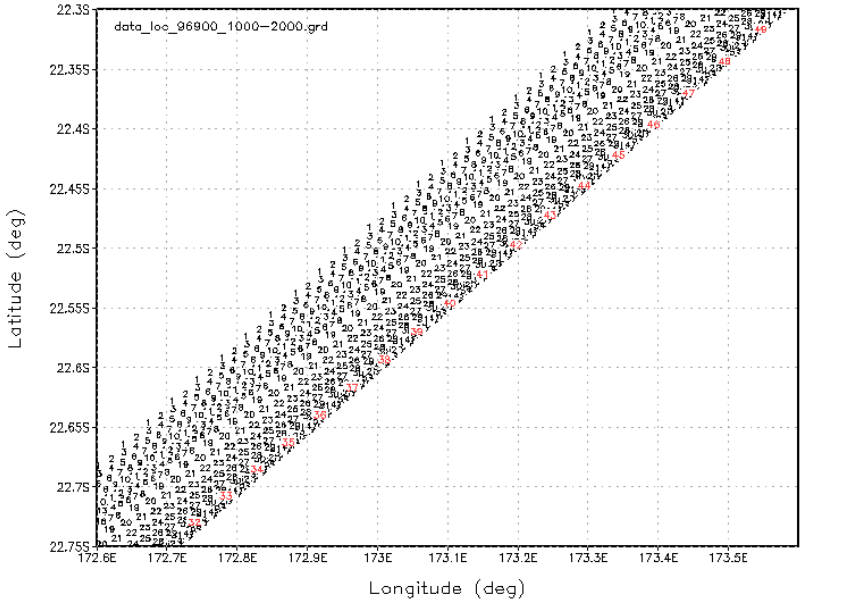


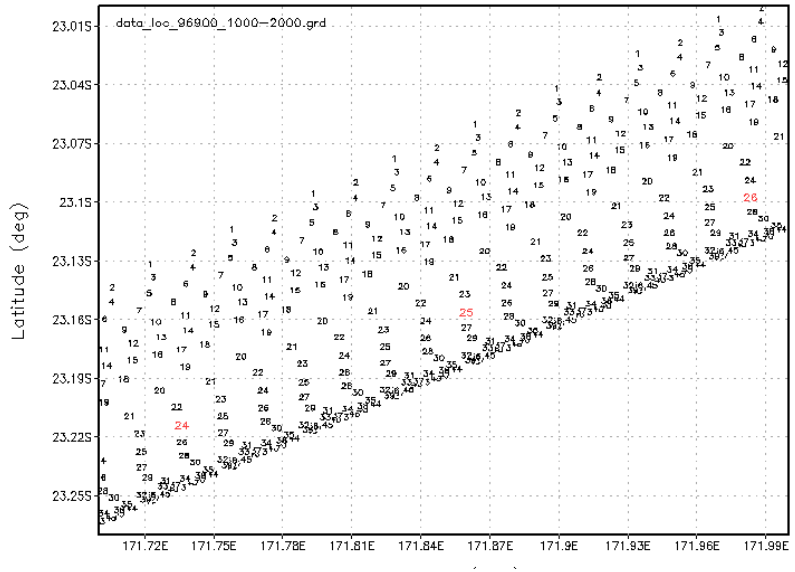
footprint trajectory (90Y） @23S



Footprint trajectory (90Y） @23S (enlarged)

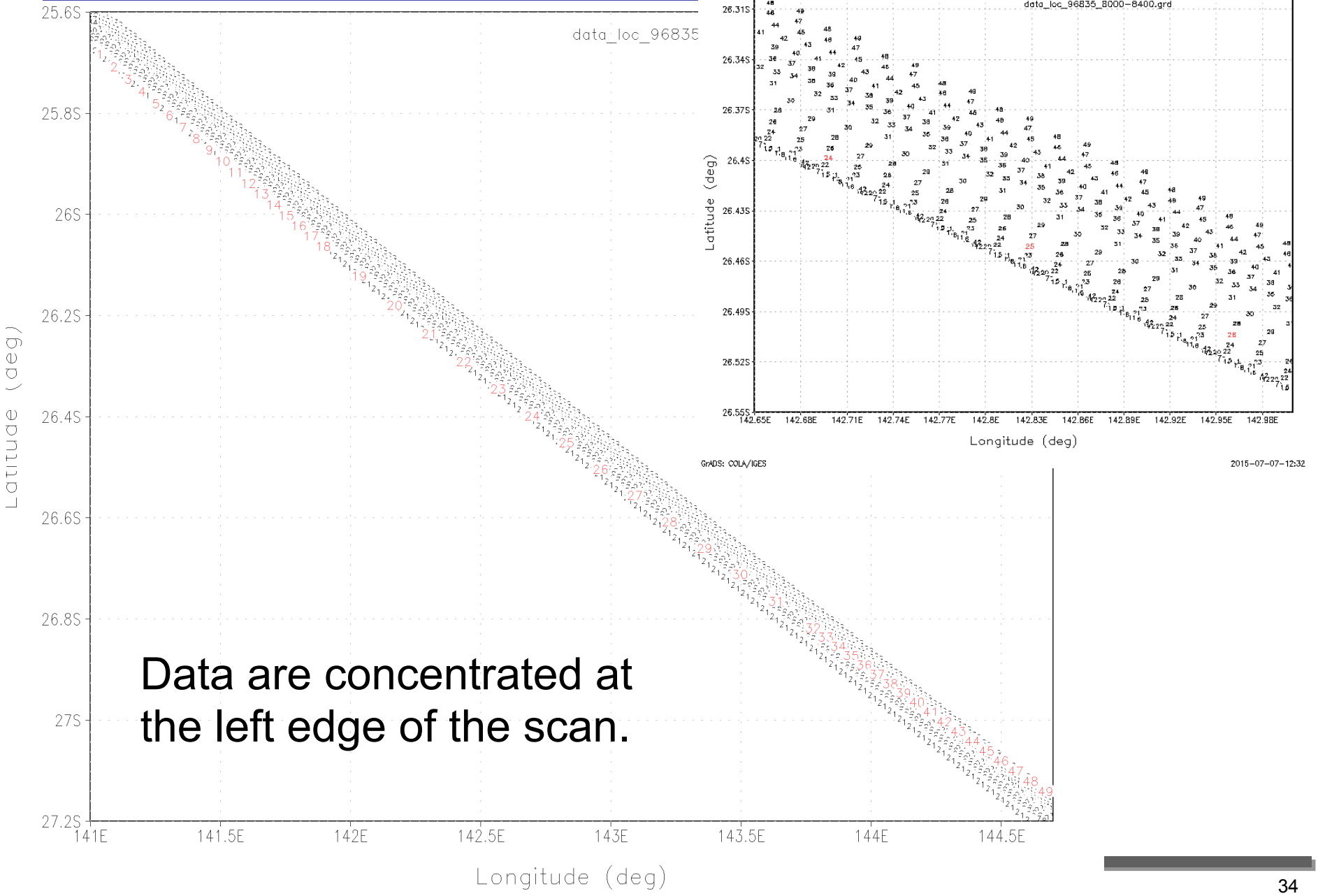






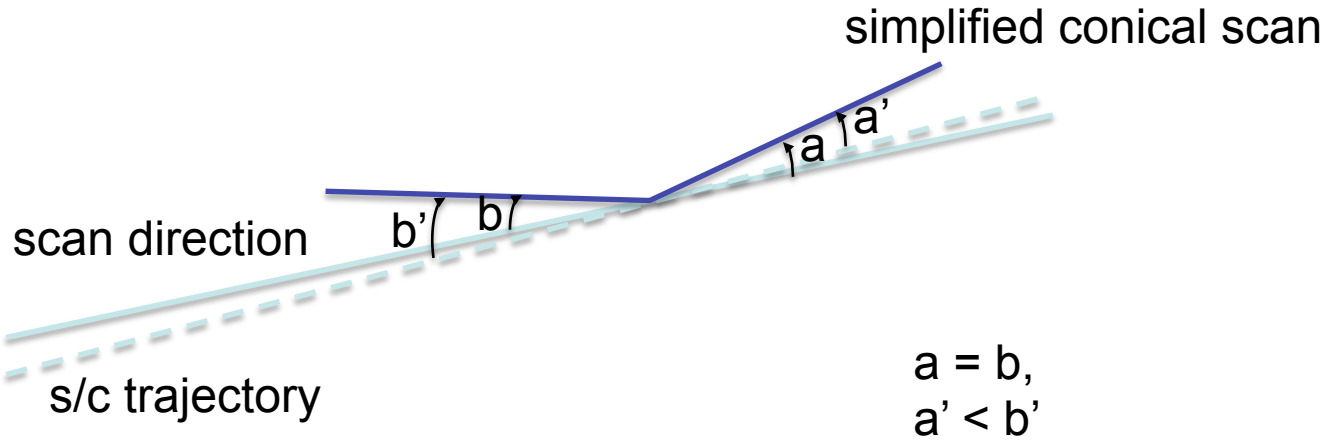
Footprints from later half of scan are concentrated at right edge. It is caused by the effect of the earth rotation and the PR's conical scan.

Footprint trajectory (descending, 90Y)



Data are concentrated at the left edge of the scan.

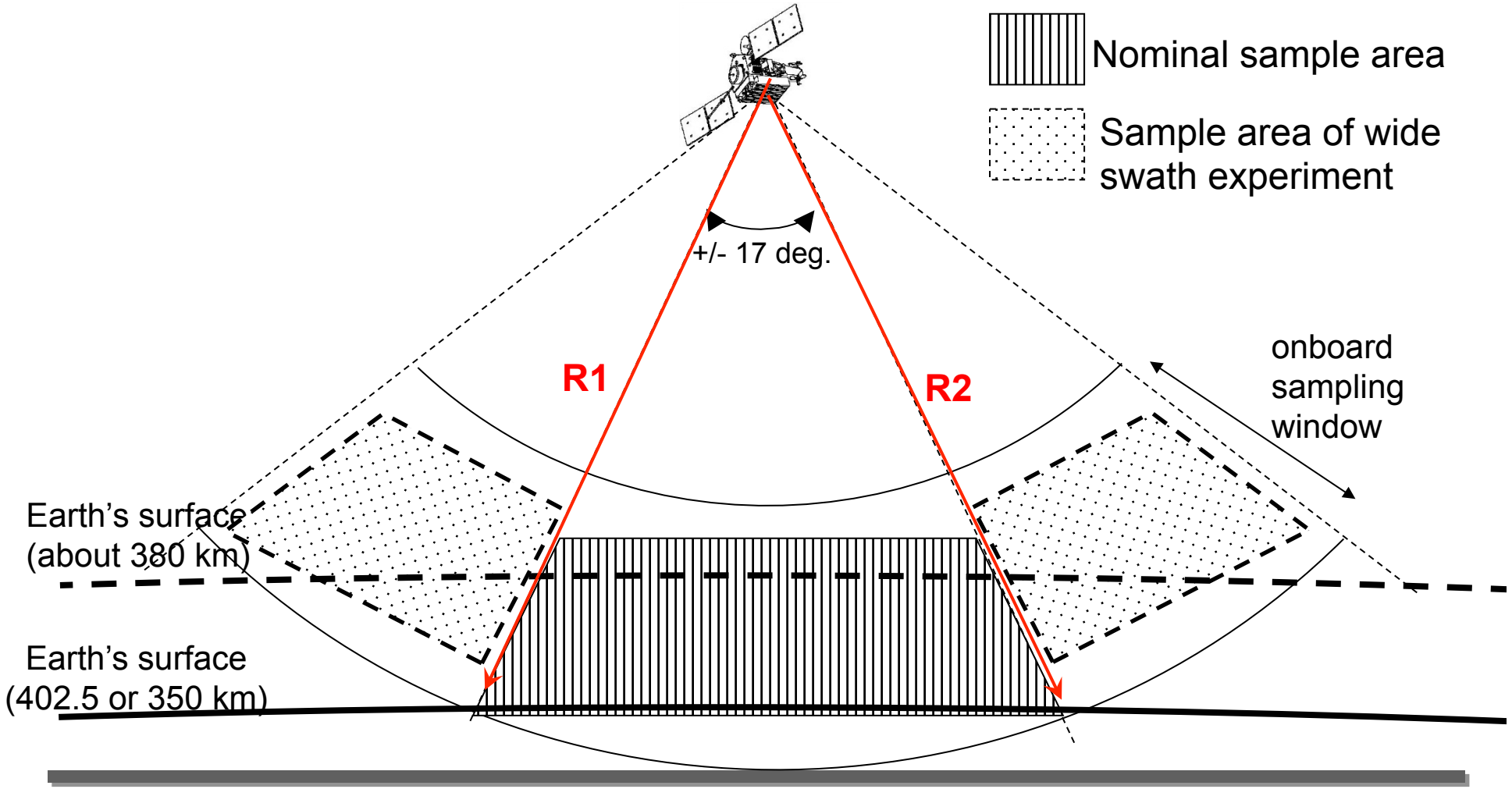
Conical scan + Earth's rotation



if a' (b') is zero, the footprints of various incident angle will be overlapped.

Satellite attitude (roll/pitch)

- Spacecraft roll can be estimated by using the surface echo distance of opposite direction. (R1 – R2)
- In the case of 90Y, R1-R2 represents the pitch offset.



wide swath case (R1-R2 and Yaw for one orbit)

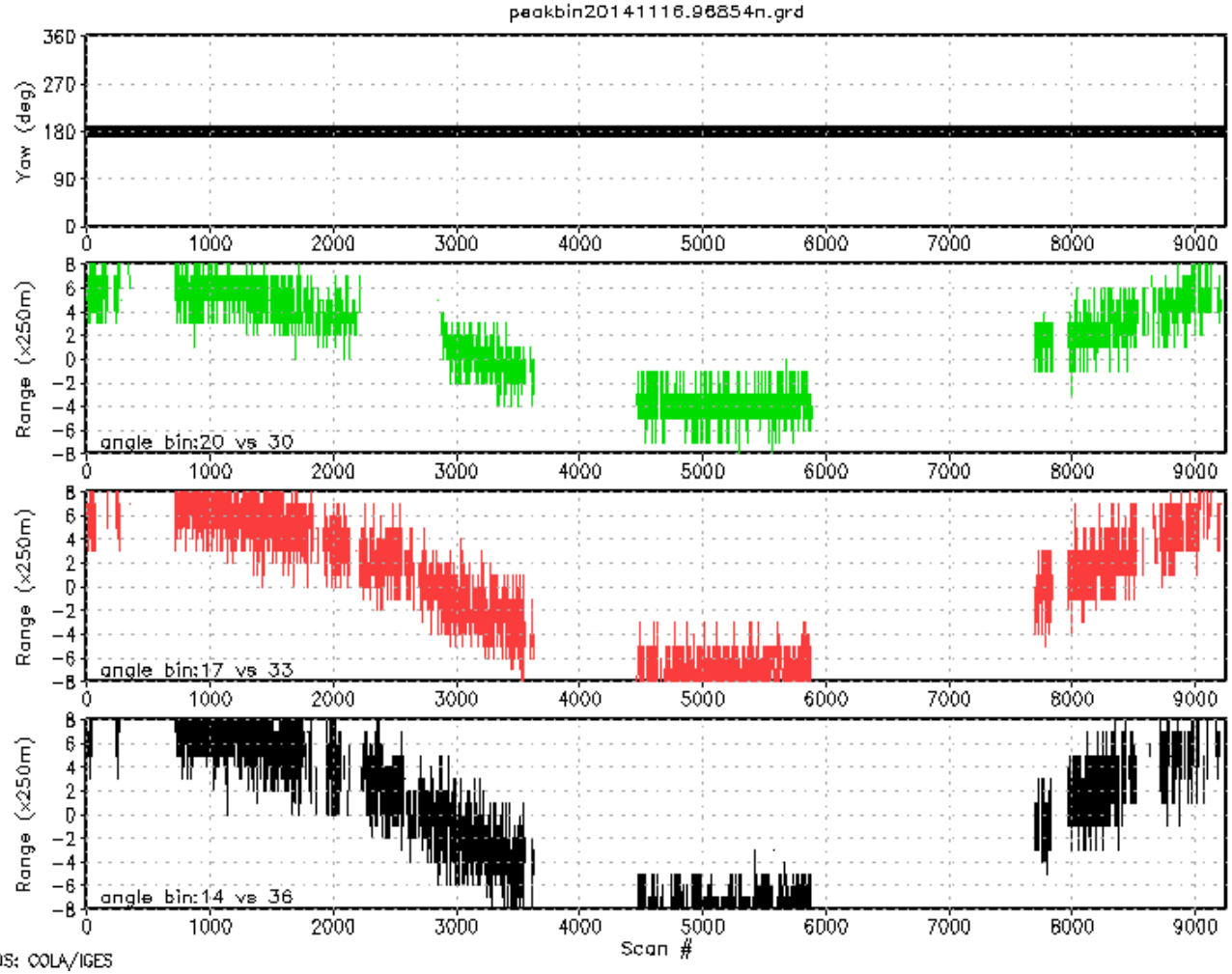
- Sinusoidal change of roll angle was seen during the orbit boot in 2001.
- It indicates the spacecraft roll adjustment did not work when the satellite altitude is between 350 and 402 km.

Yaw

R1 - R2
(angle bin 20 vs 30)

R1 - R2
(angle bin 17 vs 33)

R1 - R2
(angle bin 14 vs 36)



wide swath case (R1-R2 and Yaw for one orbit)

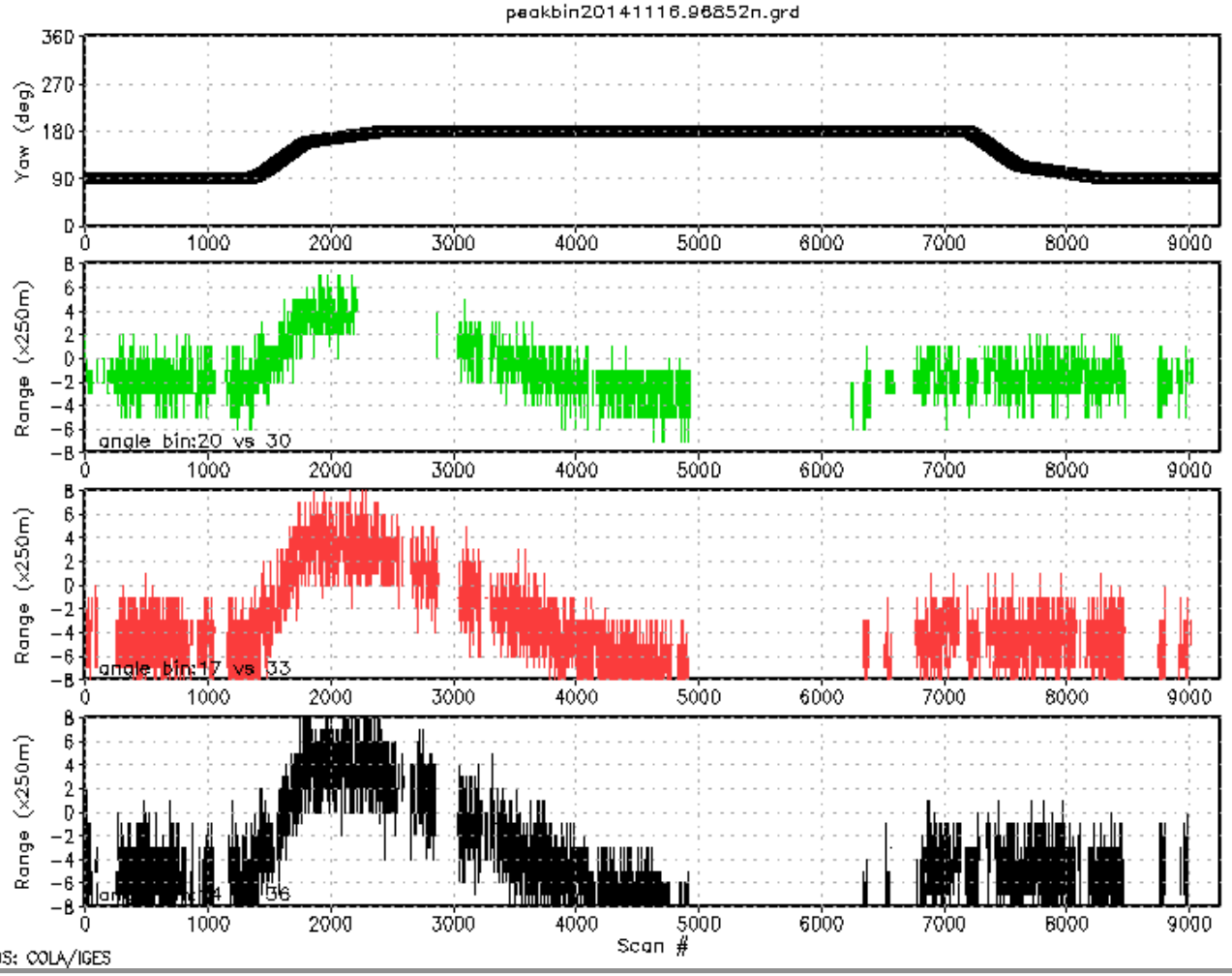
- When the yaw angle is 90 degrees, R1-R2 moves to the negative bias.

Yaw

R1 - R2
(angle bin 20 vs 30)

R1 - R2
(angle bin 17 vs 33)

R1 - R2
(angle bin 14 vs 36)

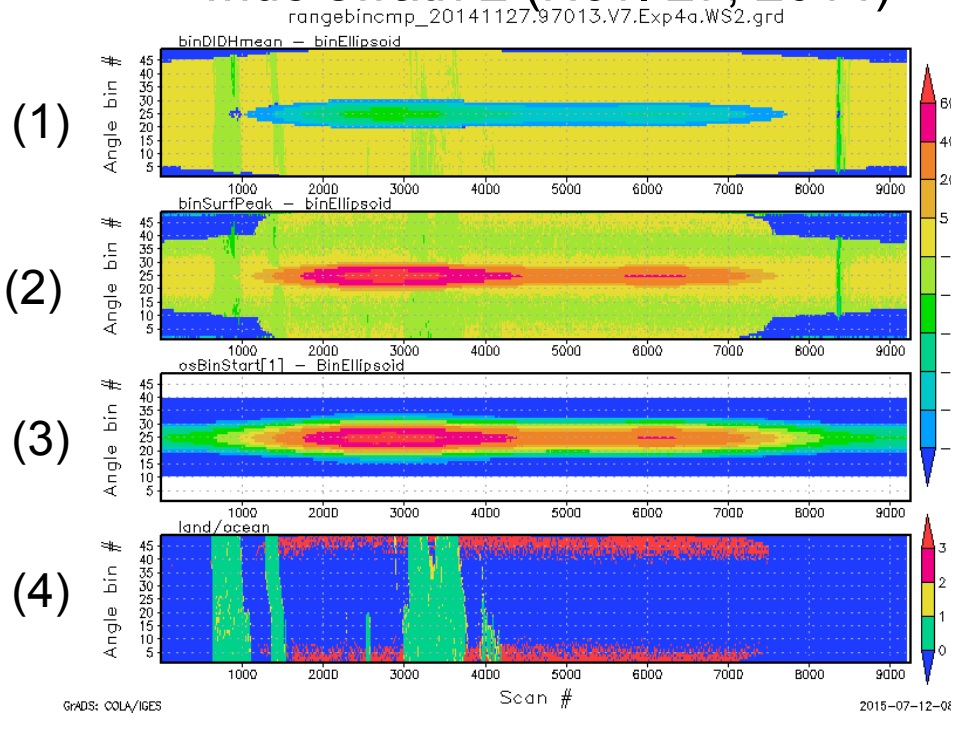


binSurfPeak, binDIDHmean, osBinStart

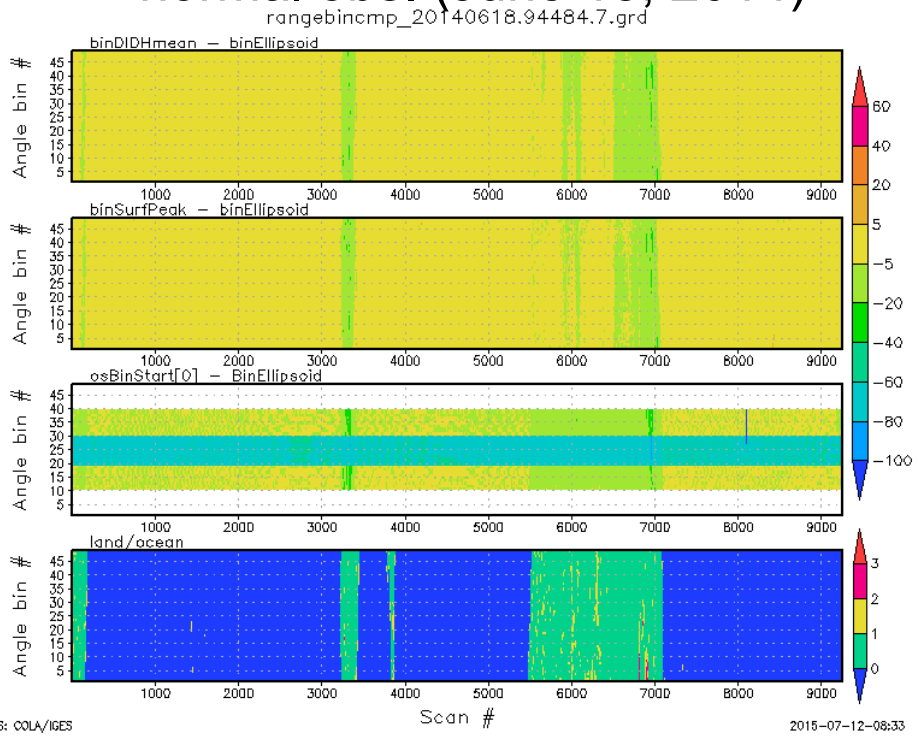
(1)binSurfPeak – binEllipsoid
(2)binDIDHmean – binEllipsoid
(3)osBinStart - binEllipsoid
(4) land/ocean flag

binEllipsoid is correctly updated for special experiments. binSurfPeak and osBinSart are depends on the onboard surface detection algorithm that assumes normal observation geometry.

wide swath 2 (Nov. 27, 2014)



normal obs. (June 18, 2014)

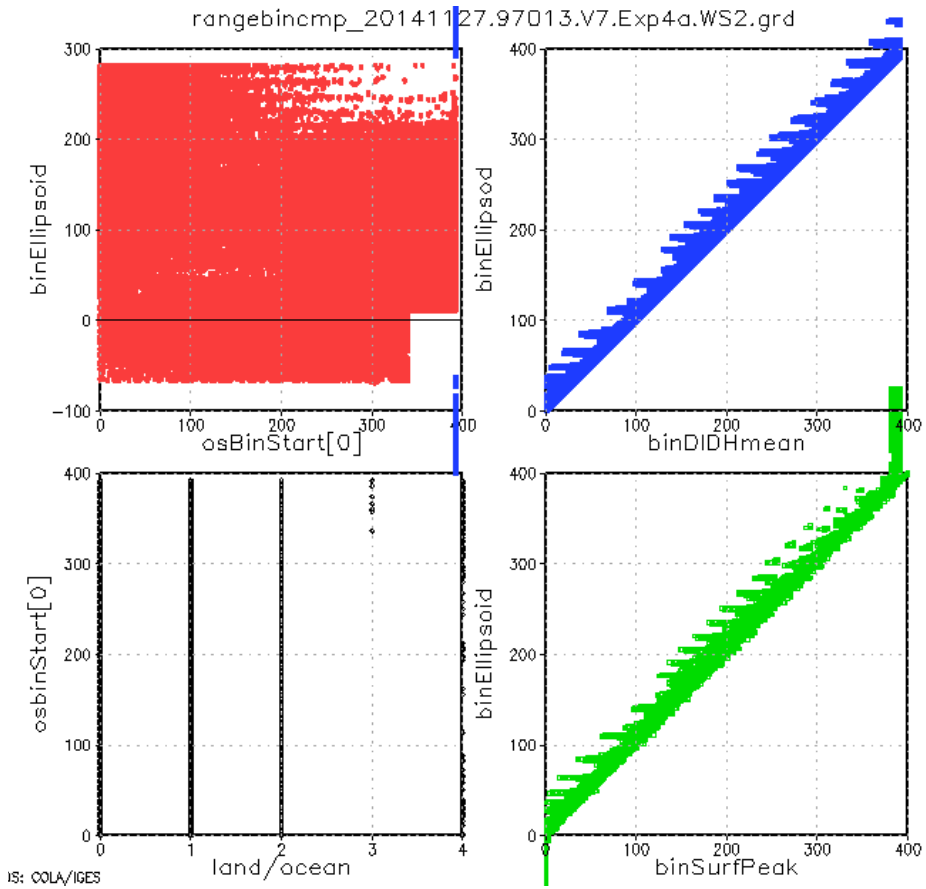


binEllipsoid: range bin of Earth's ellipsoid
binSurfPeak: surface range bin

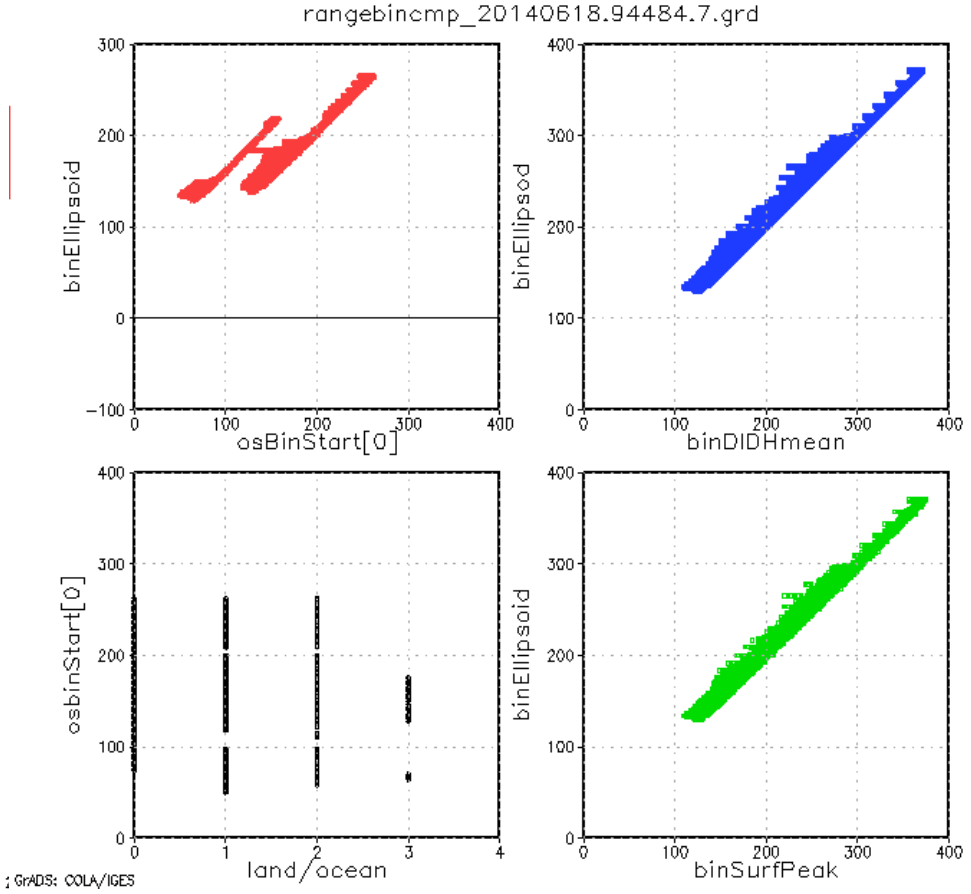
binDIDHMean: Earth's surface range bin from DEM
osBinSatrt: top range of oversampling

binSurfPeak, binDIDHmean, osBinStart (scatter plot)

wide swath 2 (Nov. 27, 2014)



normal obs. (June 18, 2014)



Outline

- *PR observation during the descent*
- *Proposed experiments and schedule*
- *Overview of each experiment*
- *Summary and discussion items*

Proposed experiments (as Dec. 2012)

		purpose	operation	risks	note
Normal observation	1 Nominal observation	1.Comparison with GPM/ DPR. 2. Increase the rain record by radar. 3. Testing GSMaP.	Nominal observation	No risk.	Retrieved data may be valid until the radar observed up to 5 km in height.
Experimental observation	2a Radiometer mode	Use the PR as radiometer	Nominal obs. and RF off.	Medium risk on the RF on/off.	During obs. window is out of the rain layer.
	2b Dense sampling	Increase the data on the non uniform beam filling effect.	External cal. mode	No risk. This mode is part of nominal obs. chain.	Need to have certain depth of rain layer.
	2c KaPR scan simulation	To obtain the reference data of KaPR scanning with Ku-band radar.	Nominal obs. Mode with modified phase code	Minor risk. Need to upload the phase data.*	Need to have certain depth of rain layer.
	2d Wider swath experiment	To check the possibility to enlarger the swath	External cal. mode or Nominal obs. Mode	Minor risk. Need to upload the phase data.	This mode is available when the obs. Window covers only near surface.
Experimental observation w/ modified satellite operation	3a 90 deg. yaw observation	To obtain the detailed rain structure and sigma zero	Nominal obs. mode with satellite yaw angle of 90 deg.	Unknown risks for 90 deg. yaw operation.	Unknown impacts to other instruments (TMI, VIRS, LIS)
	3b Pitch maneuver	To obtain the clutter data against pitch angle.	Nominal obs. mode with pitch angle of 0.5 to 4 degrees.	Less risk to S/C. Negligible impact to TMI algorithm.	Useful for the antenna design of spaceborne radar
Engineering experiment	4 checkout	To obtain the engineering information of PR	Various modes	Unknown risk.	Need to limit the checkout items to avoid risks.

*: This mode was tried and succeeded in the previous experiment.

Proposed experiments (as Jul. 2014)

		purpose	operation	risks	note
Normal observation	1 Nominal observation	1.Comparison with GPM/ DPR. 2. Increase the rain record by radar. 3. Testing GSMaP.	Nominal observation	No risk.	Retrieved data may be valid until the radar observed up to 5 km in height.

(Enough data can be obtained without RF off during descending)

Experimental observation	2 b Dense sampling	Increase the data on the non uniform beam filling effect.	External cal. mode	No risk. This mode is part of nominal obs. chain.	Need to have certain depth of rain layer.

(2b can cover this experiment)

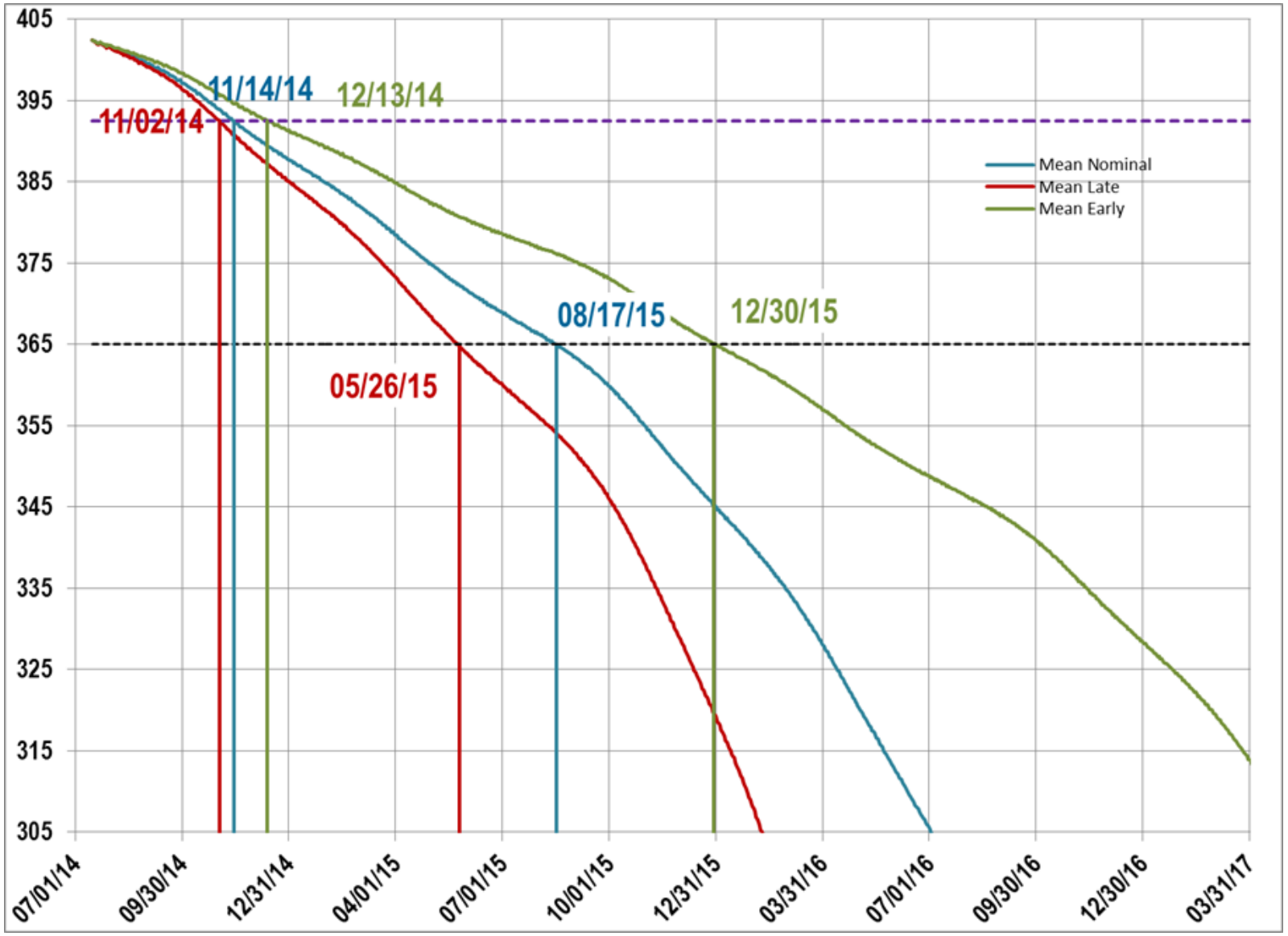
Experimental observation w/ modified satellite operation	2 d Wider swath experiment	To check the possibility to enlarger the swath	External cal. mode or Nominal obs. Mode	Minor risk. Need to upload the phase data.	This mode is available when the obs. Window covers only near surface.
	3 a 90 deg. yaw observation	To obtain the detailed rain structure and sigma zero	Nominal obs. mode with satellite yaw angle of 90 deg.	Unknown risks for 90 deg. yaw operation.	Unknown impacts to other instruments (TMI, VIRS, LIS)

(DPR has already done this experiment)

Engineering experiment	4 checkout	To obtain the engineering information of PR	Various modes	Unknown risk.	Need to limit the checkout items to avoid risks.

*: This mode was tried and succeeded in the previous experiment.

Satellite altitude prediction by NASA (as July 2014)



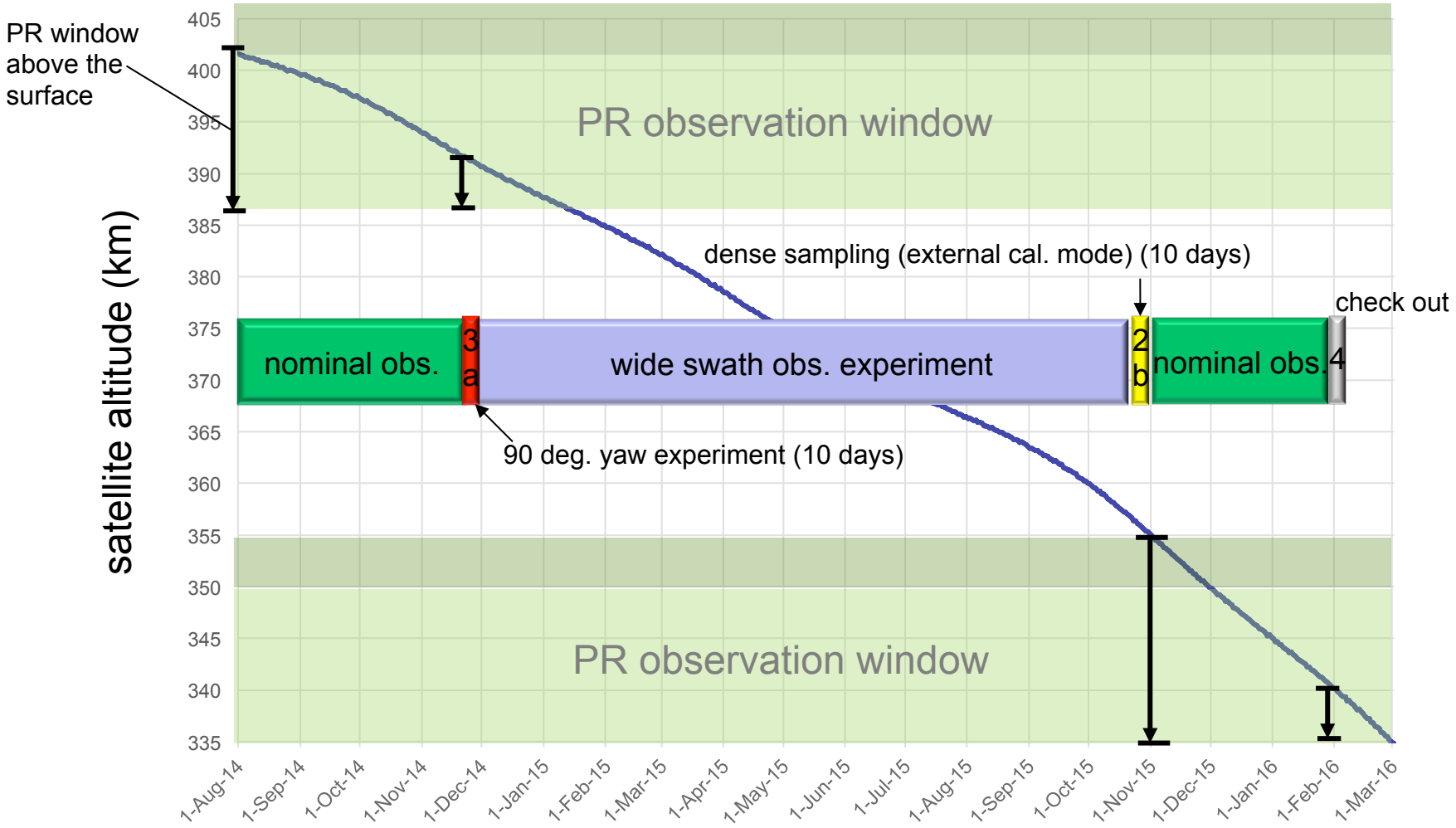
Risk assessment (as Dec. 2012)

		purpose (scientific significance)	operation (duration)	impact to S/C and instruments (risks)	note	Priority
1	Nominal observation	1.Comparison with GPM/DPR. 2. Increase the rain record by radar. 3. Testing GSMaP. **(High)**	Nominal observation (As long as the obs. window covers surface to 5km)	No risk. **(Low)**	Retrieved data may be valid until the radar observed up to 5 km in height.	**1**
2 a	Radiometer mode	Use the PR as high resolution radiometer to compare with TMI. **(Medium)**	Nominal observation and RF off. (see note)	Medium risk on the RF on/off. (Medium)	During obs. window is out of the rain layer.	**3**
2 b	Dense sampling	Increase the data on the non uniform beam filling effect for DPR L2. **(High)**	External cal. mode (10 days)	No risk. This mode is part of nominal obs. chain. **(Low)**	Need to have certain depth of rain layer.	**1**
2 c	KaPR scan simulation	To obtain the reference data of KaPR scanning with Ku-band radar. **(Medium)**	Nominal obs. Mode with modified phase code. (10 days)	Minor risk. Need to upload the phase data.* **(Low)**	Need to have certain depth of rain layer.	**2**
2 d	Wider swath experiment	To check the possibility to enlarger the swath for future radar design.**(High)**	External cal. mode or Nominal obs. Mode (10 days)	Medium risk. Need to upload the phase data. **(Medium)**	This mode is available when the window is out of the rain layer.	**2**
3 a	90 deg. yaw observation	To obtain the detailed rain structure and sigma zero **(High)**	Nominal obs. mode with satellite yaw angle of 90 deg. (total 10 days)	Unknown risks for 90 deg. yaw operation for S/C. **(High)**	Unknown impacts to other instruments (TMI, VIRS, LIS)	**3**
3 b	Pitch maneuver	To obtain the clutter data against pitch angle. **(Medium)**	Nominal obs. mode with pitch angle of 0.5 to 4 degrees w/ 0.5 deg. intervals. (minimum 2 days)	Less risk to S/C. Negligible impact to TMI algorithm. **(Low)**	Useful for the antenna design of spaceborne radar	**2**
4	checkout	To obtain the engineering information of PR. **(Low)**	Various modes (1 -2 weeks)	Unknown risk. **(Medium to High)**	Need to limit the checkout items to avoid risks. (implement at the end of the PR experiments)	**4**

*: these modes were tried and succeeded in the previous experiment.

Experiment plan

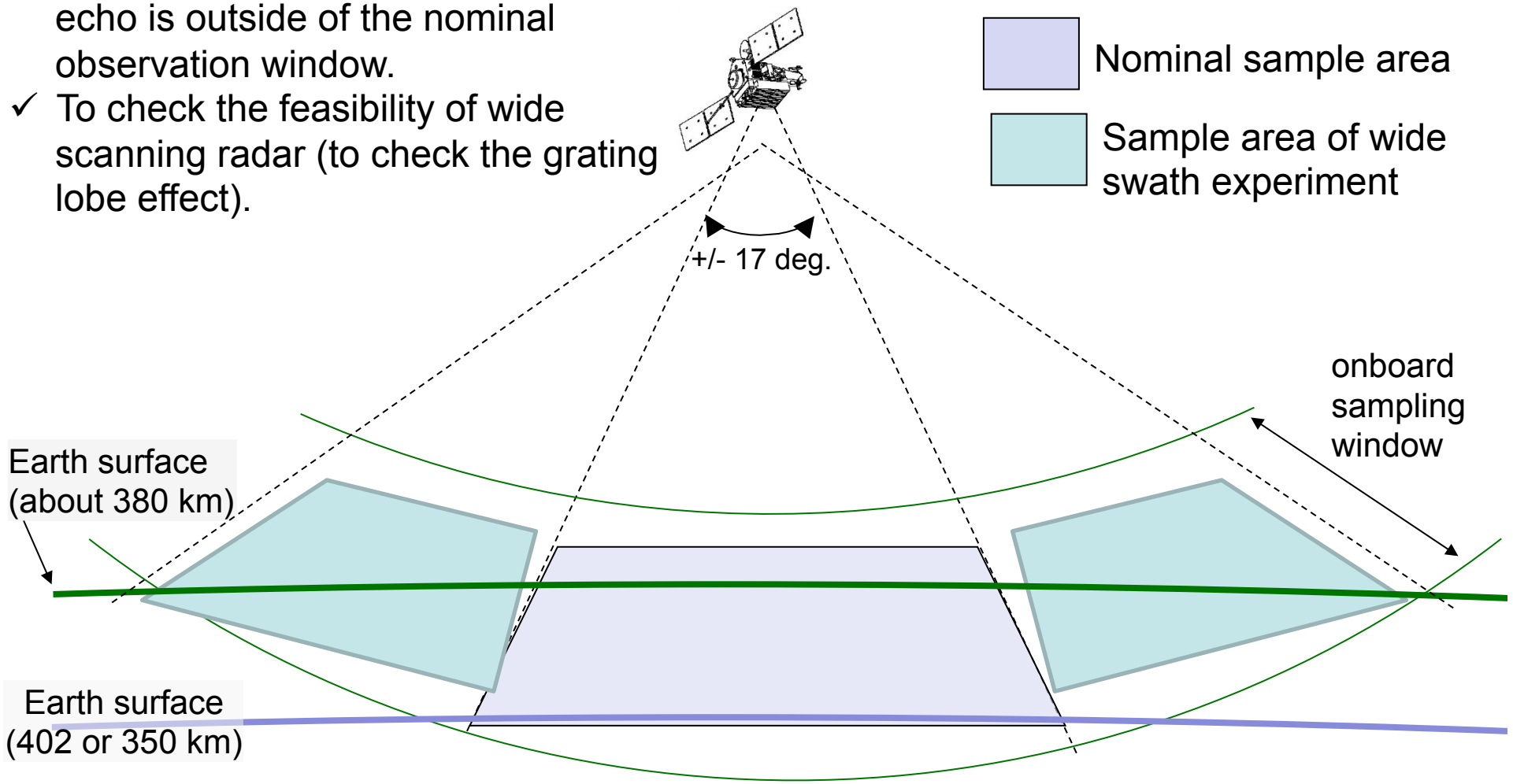
- nominal altitude prediction case



2d Wide swath experiment

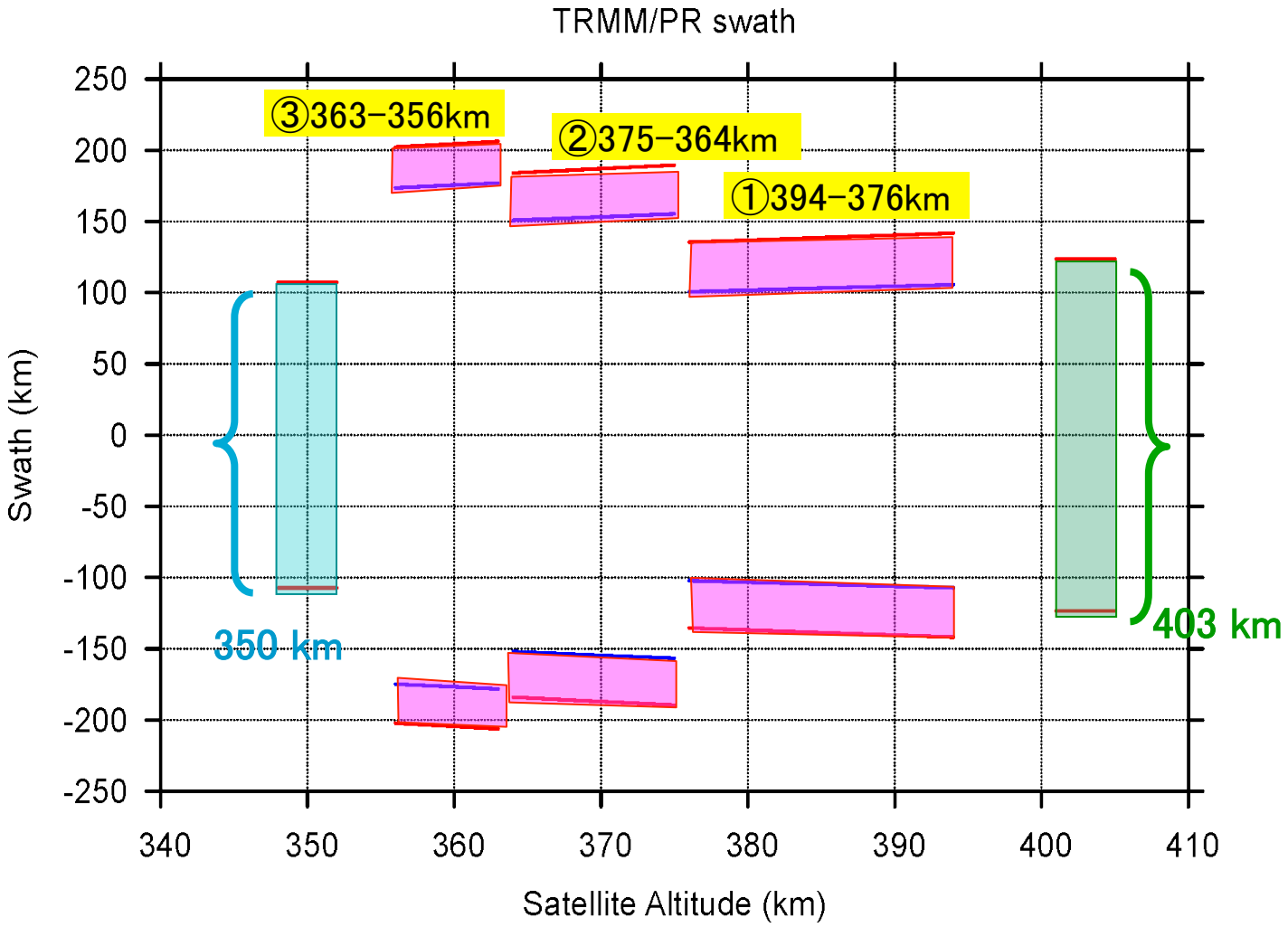
Implemented when the satellite altitude is between 390 and 355 km

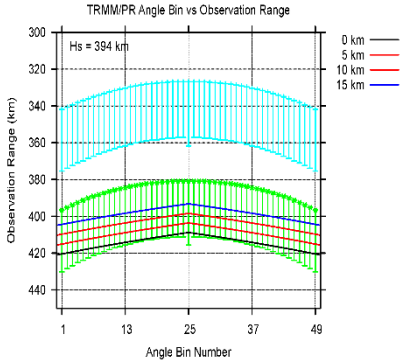
- ✓ To observed rain echo where rain echo is outside of the nominal observation window.
- ✓ To check the feasibility of wide scanning radar (to check the grating lobe effect).

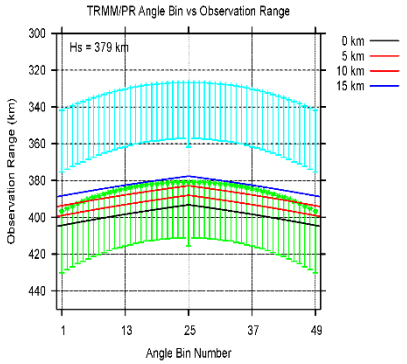


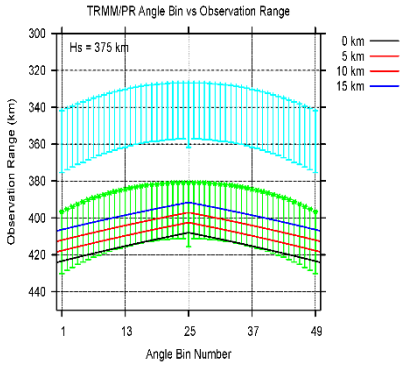
Swath widths during the experiment

(H. Hanado, 2013)



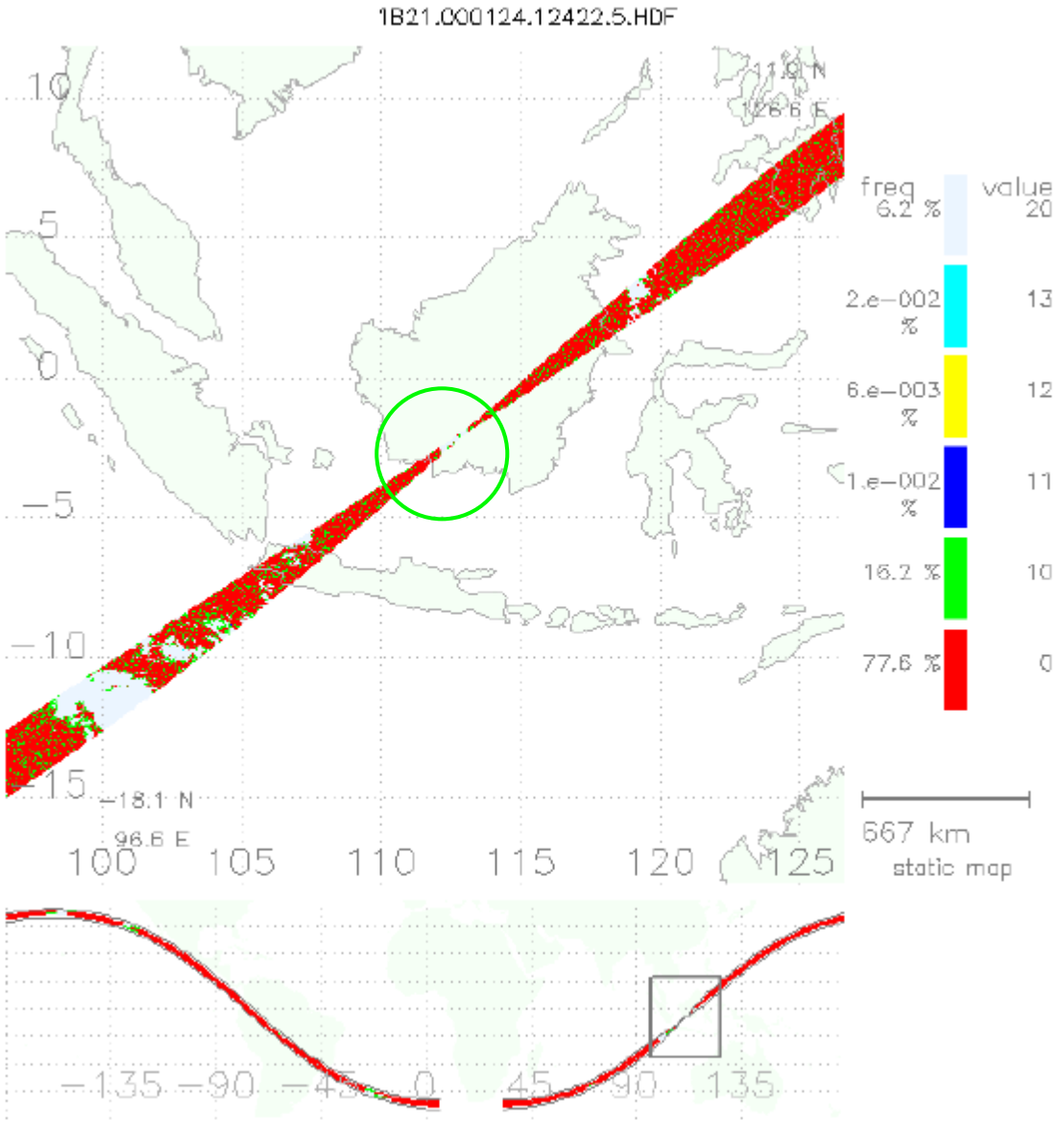


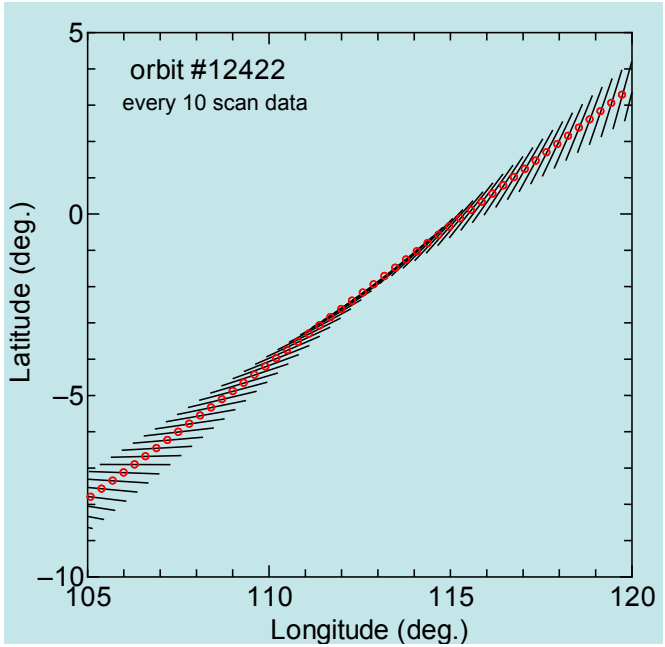


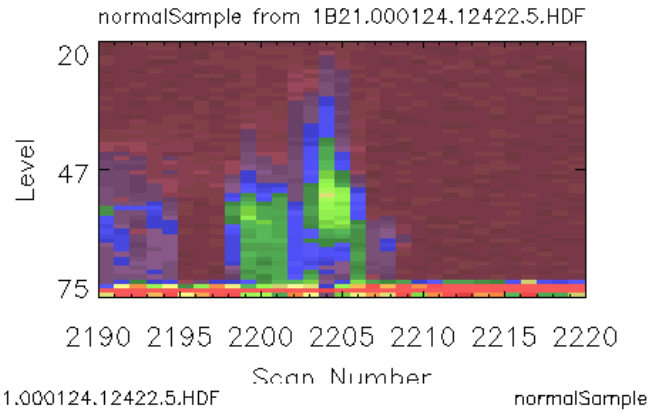


- Issues:
  - Higher main lobe clutter
  - Grating lobe effect

180 deg. Yaw example (2000.1.24 orbit #12422)





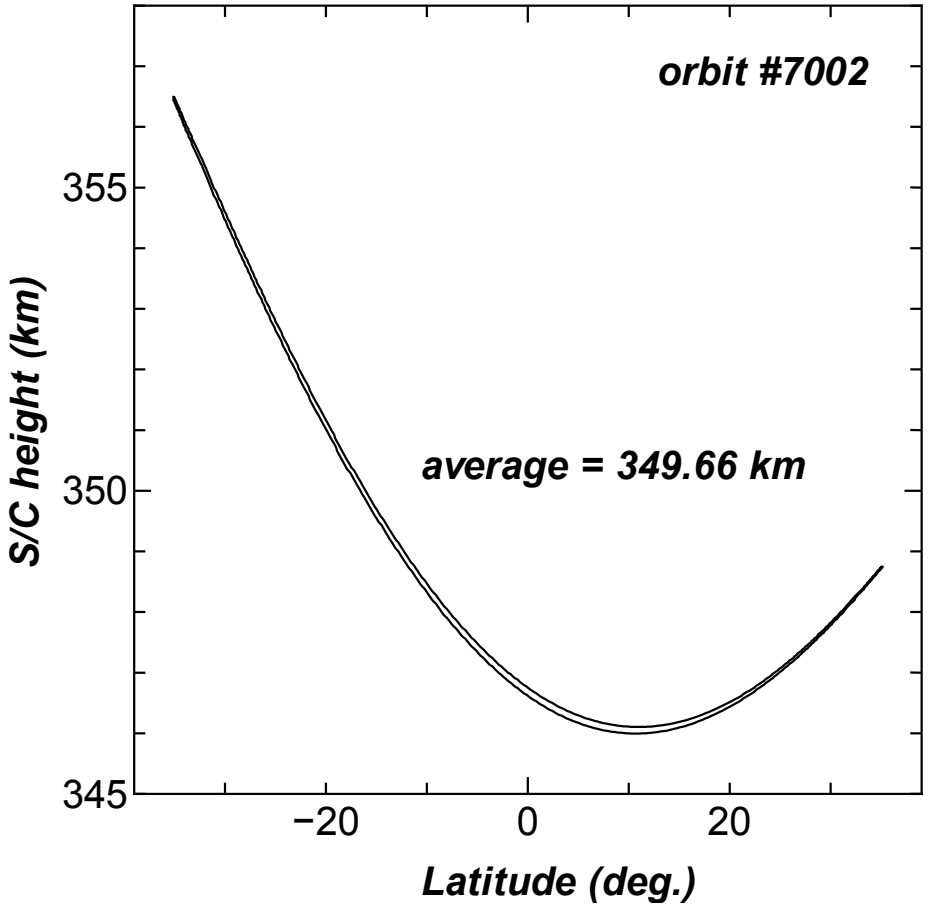


Summary and discussion items

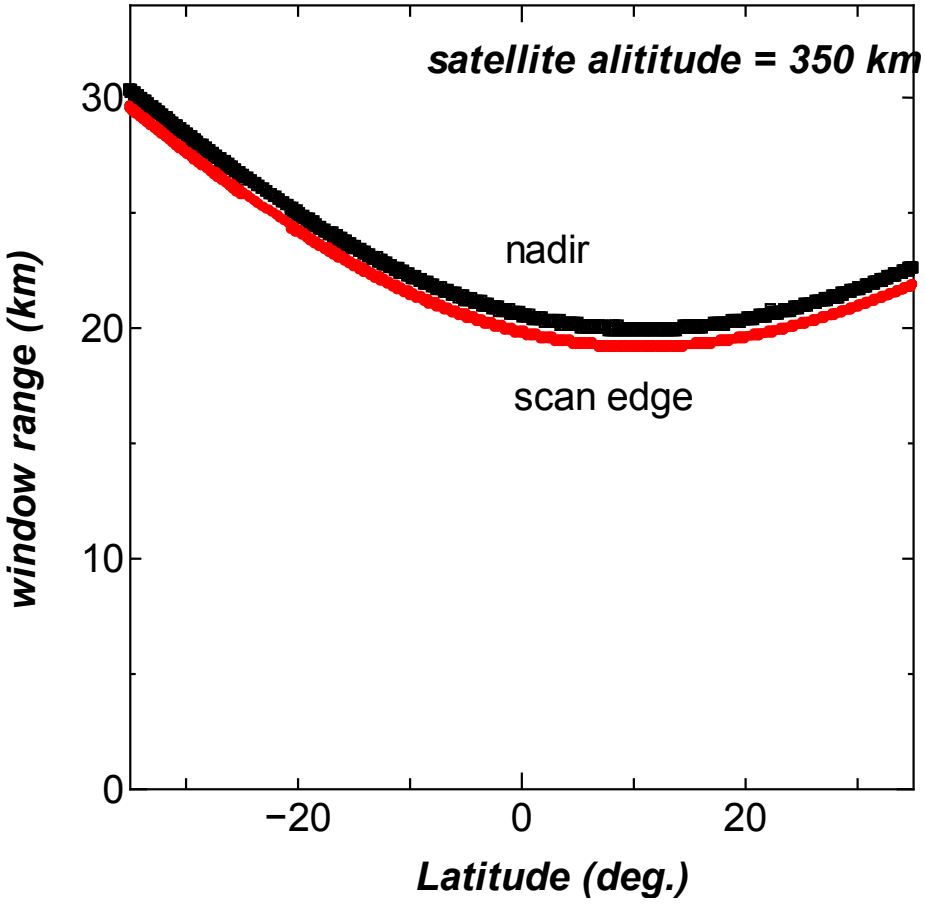
- Summary: proposed experiments:
  - Dense data sampling with external calibration mode (10 days in 392-390 km)
  - Wider swath experiment (390-355 km)
  - 90 deg. yaw maneuver experiment (10 days in 390-355 km). Combination of wider swath experiment is preferable.
- Impact to the other sensors and satellite bus
  - Need a special operation during the 90 deg. yaw maneuver. TMI's scan direction will be also fore- and aft-looking observation. Note that NASA ESMO team has checked the feasibility of the experiment.
  - Feedback from TMI team: it is required to avoid this experiment when the satellite altitude approaches to near 350 km.
- Discussion items:
  - timing of 90 deg. yaw experiment (current proposal is when the both the nadir and the wider scan observation is available. e.g. between 390 and 380 km.
  - Need to determine the priority of the sensor in case the battery 2 is degraded more.

Backup slides

Example of observable window vs. latitude

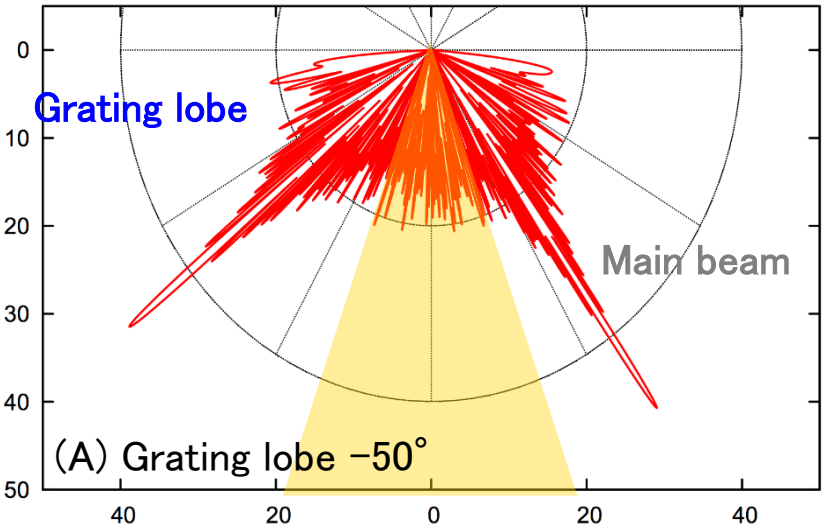


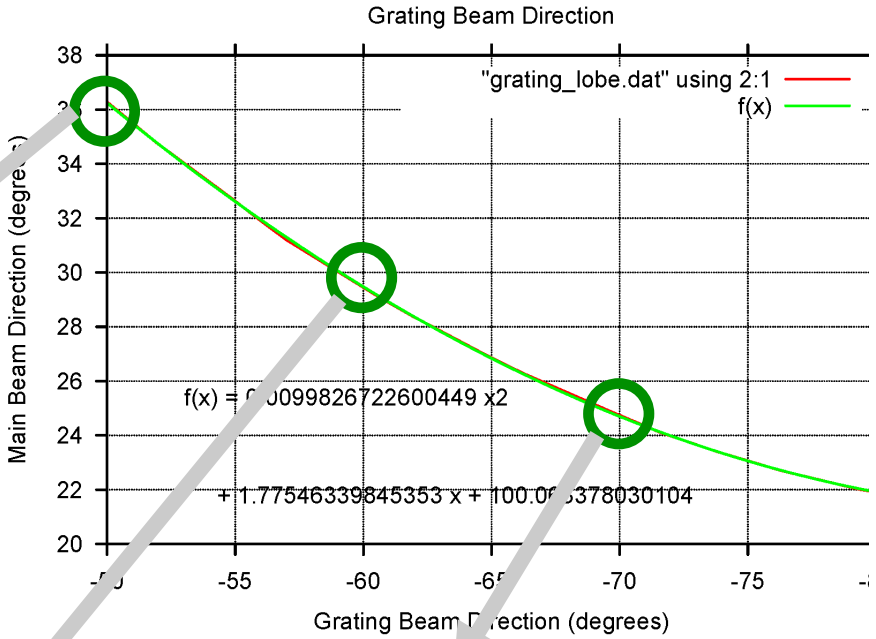
Satellite altitude relative to the Earth surface.
(fluctuation: 10 km range)

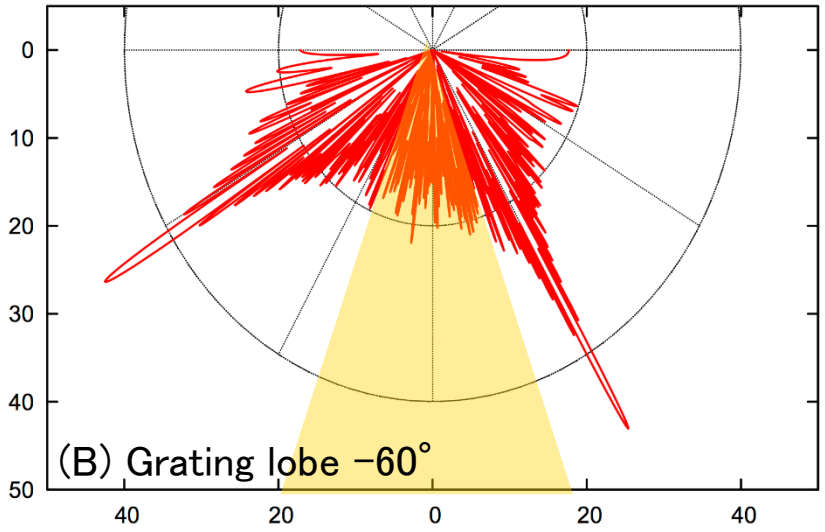


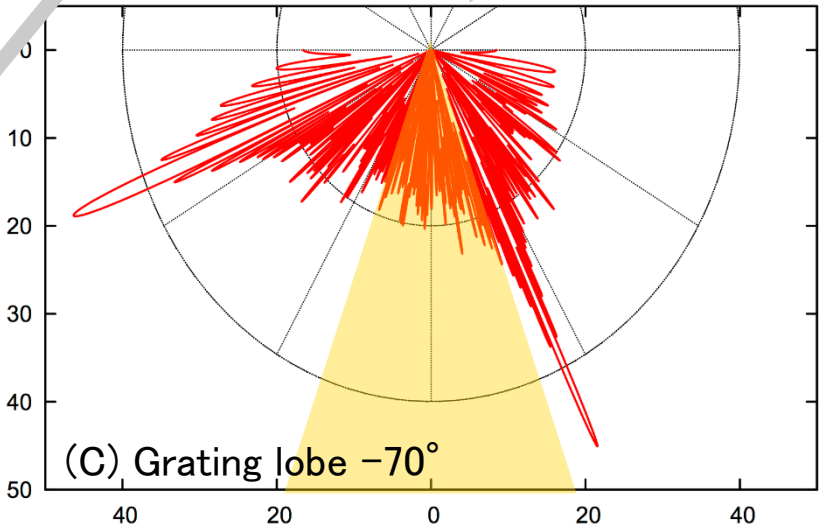
Observation window
(above the Earth surface)
Nadir vs. scan edge

Grating lobes of TRMM/PR (H. Hanado, 2013)

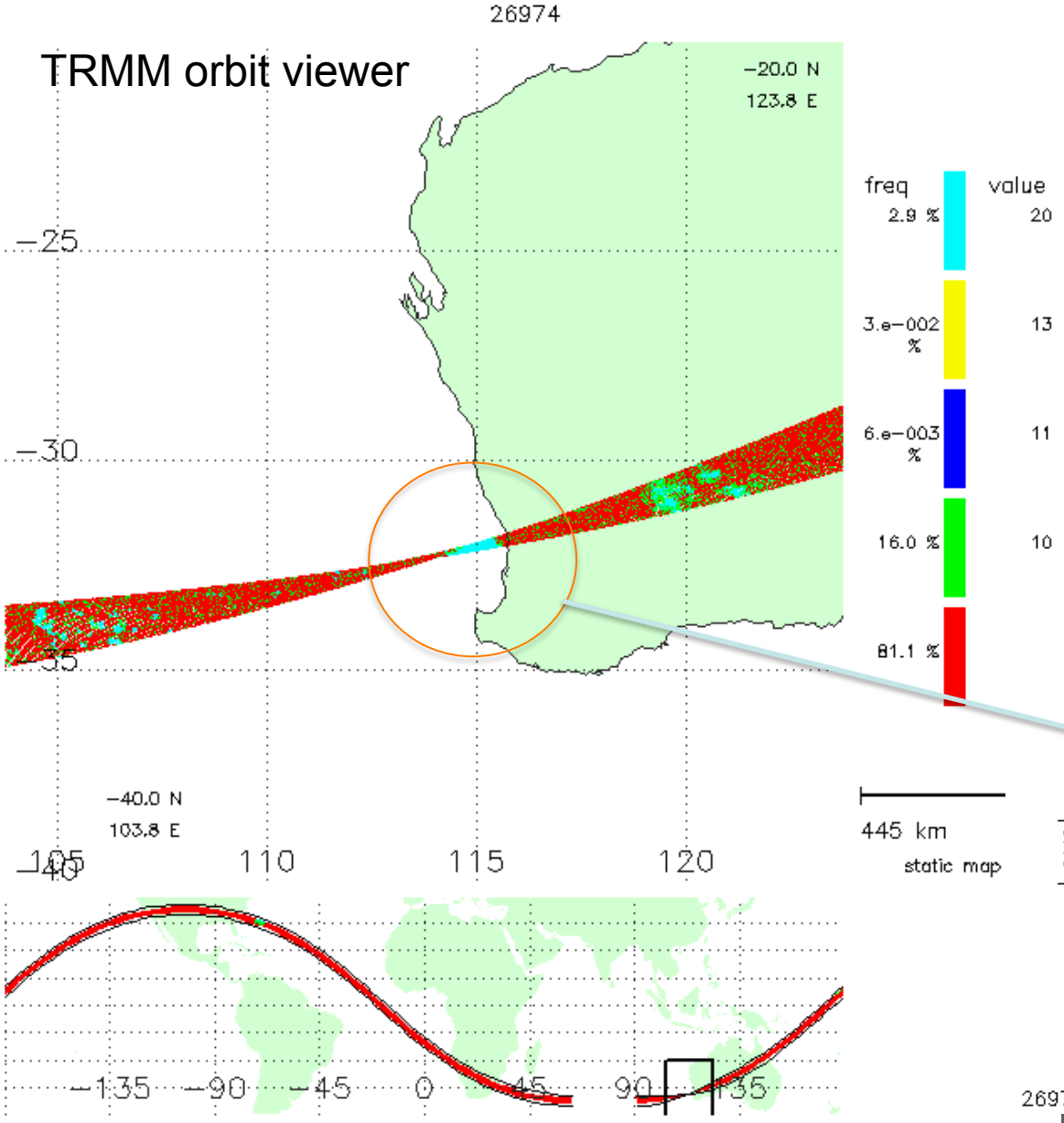






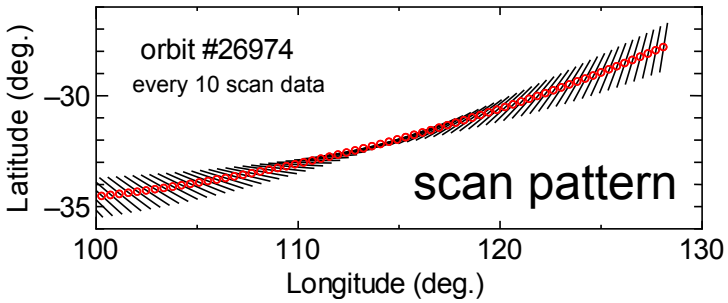


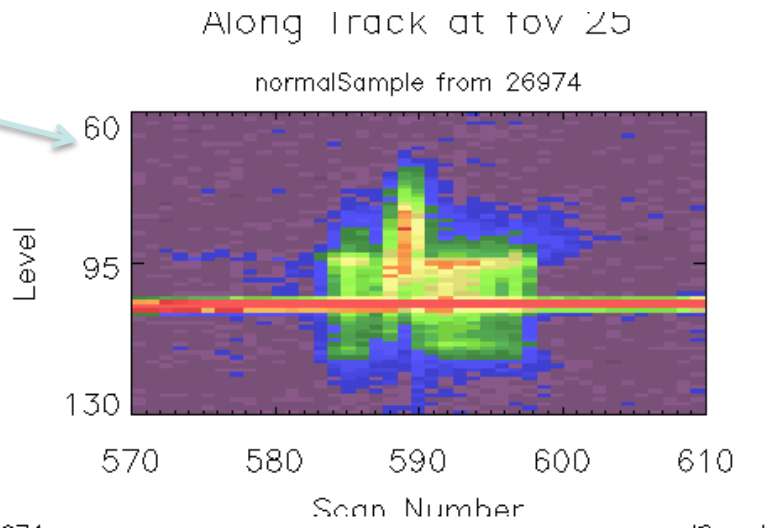
180 deg. yaw maneuver data analysis



Takahashi and Iguchi, 2007 (IGARSS)

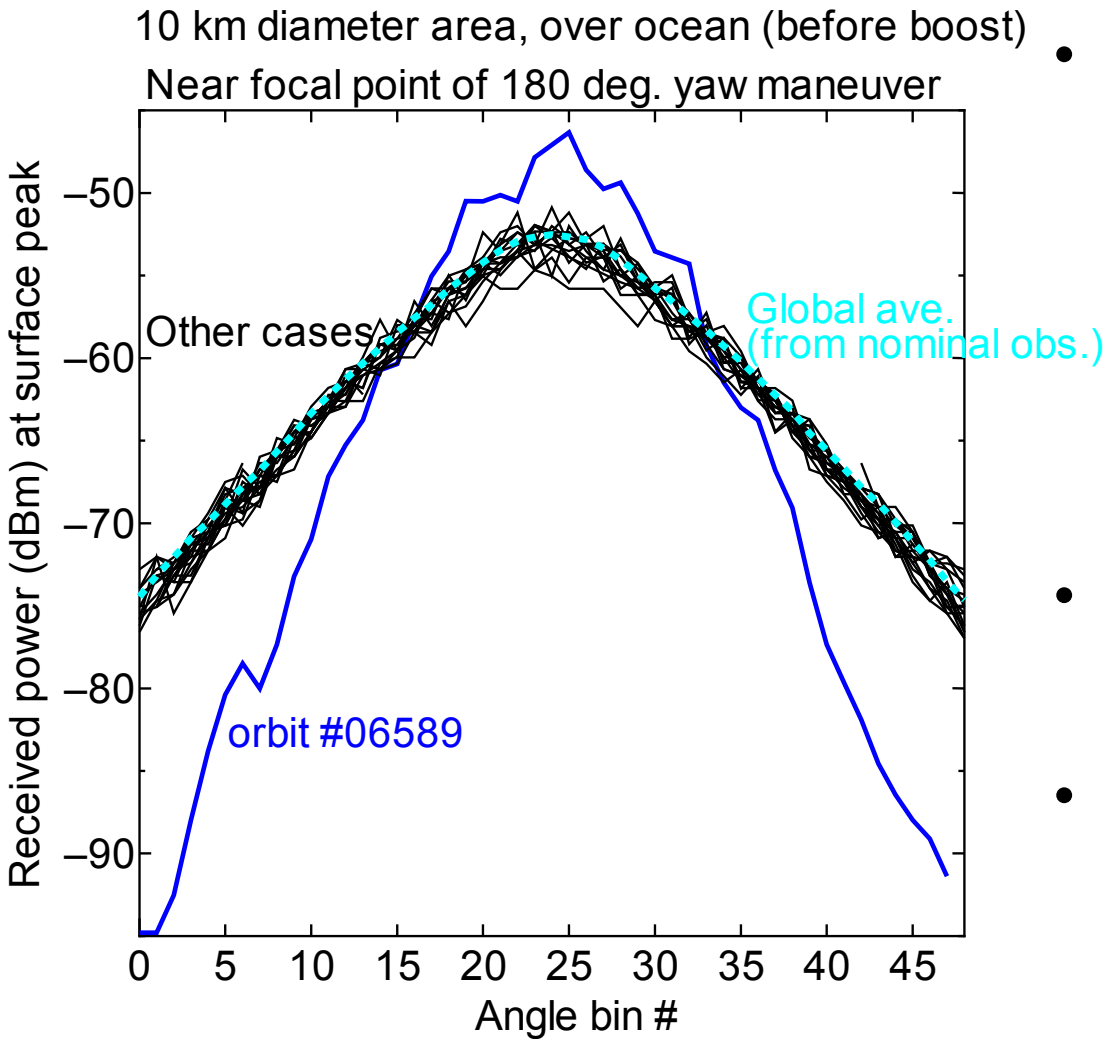
case: 2002.8.8 orbit #26974





Sea surface echo (sigma-0)

Sample sea surface echo for various incident angles within very limited area.

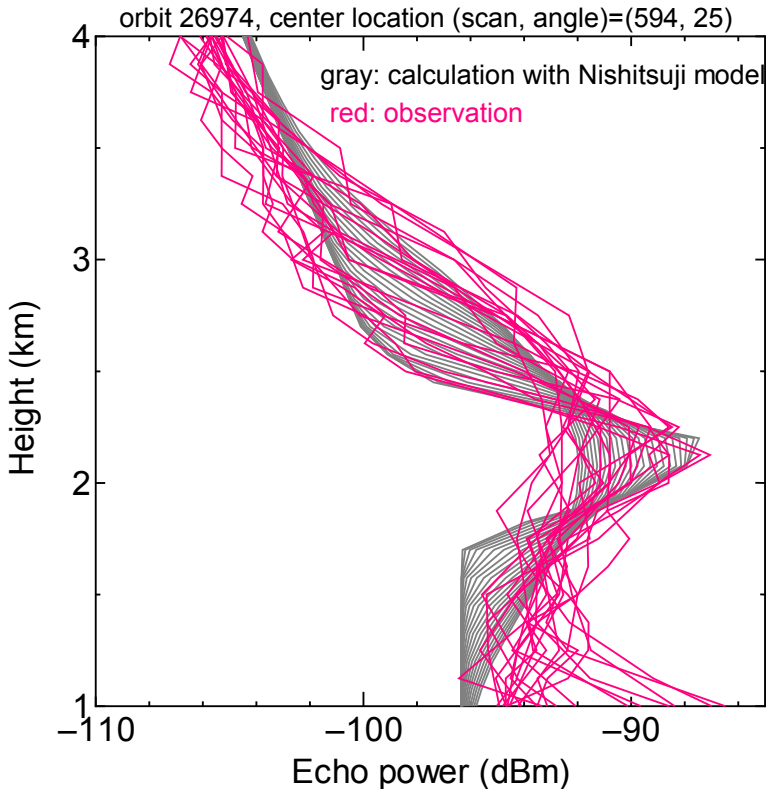


- One case with weak surface echo at the scan edge is found among yaw turn data
  - orbit #06589, 1999.1.19 @ Indian Ocean)
  - Weak power at scan edge & high power near nadir appears at the same time.
- Indication of smooth surface condition (#06589)
- Sea surface wind speed data (e.g. TMI, SSM/I) support this result (weak wind speed at this area).

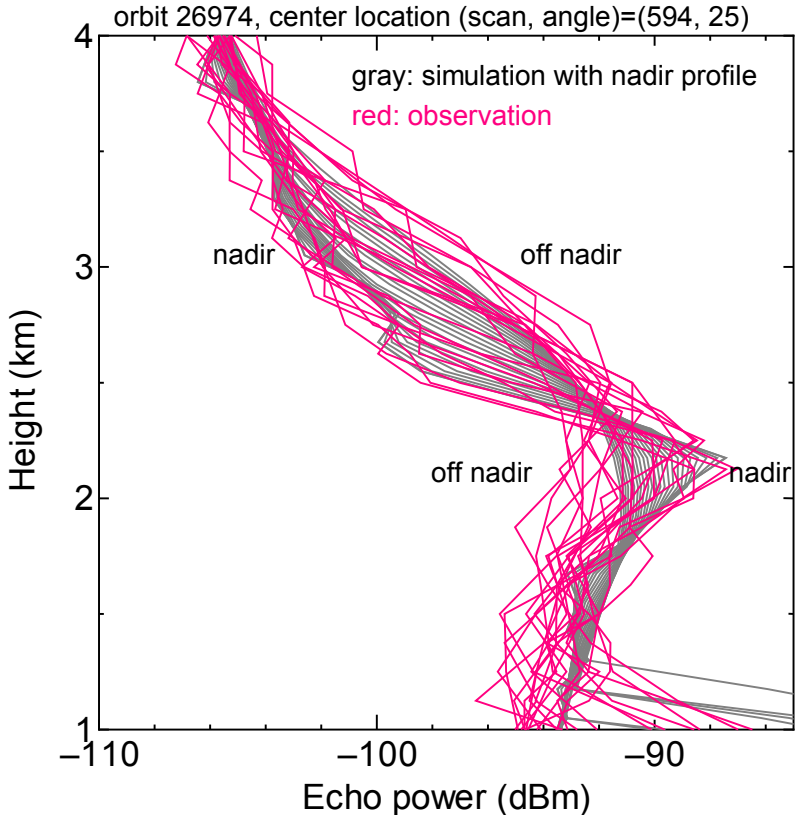
Bright band profile for various incident angles

Angle bin dependency of BB structure.

observation (red) vs.
bright band model (grey)



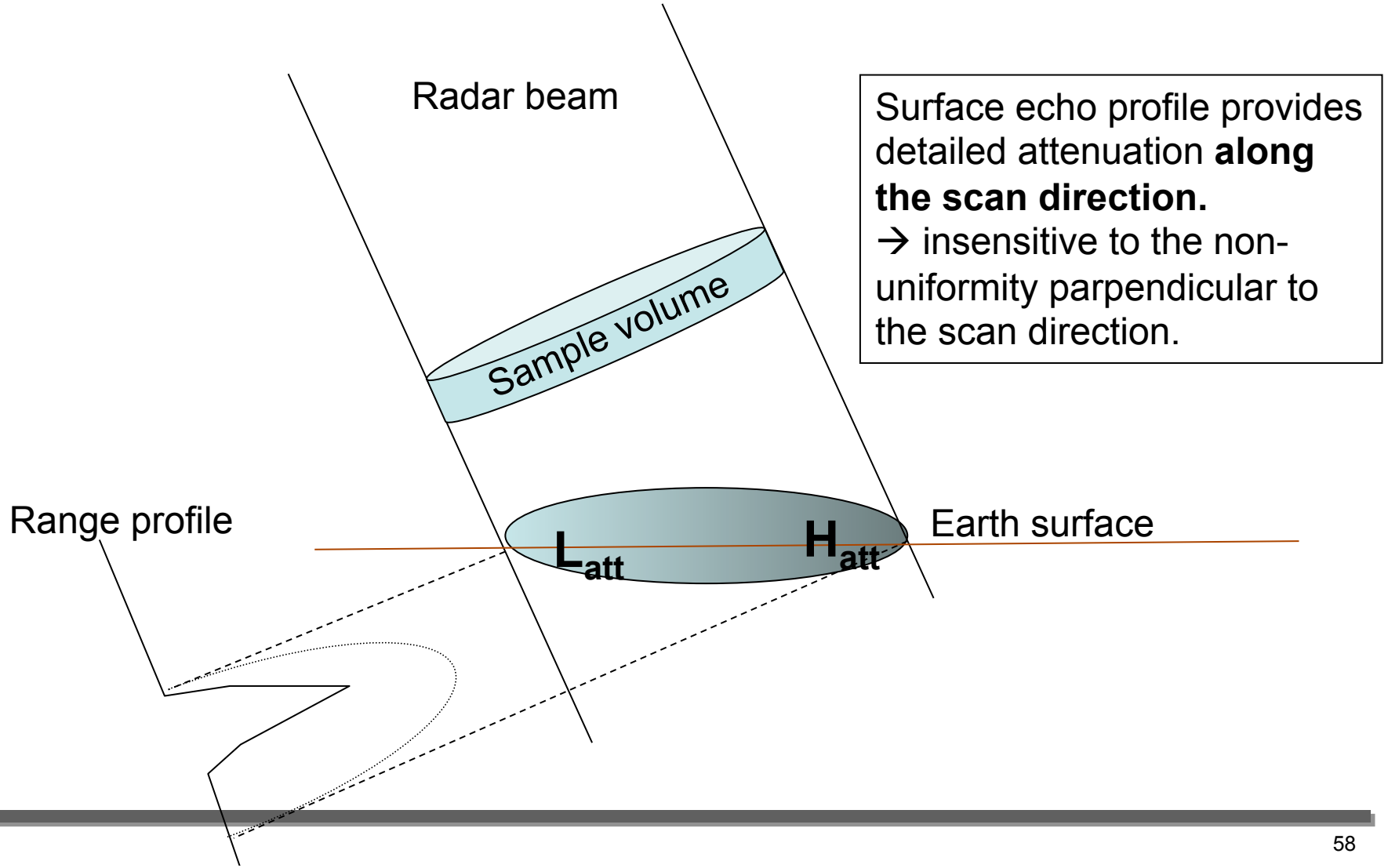
observation (red) vs. simulation
with nadir profile data (grey)



Tendency of angle bin dependency is similar to the model but wider fluctuation.

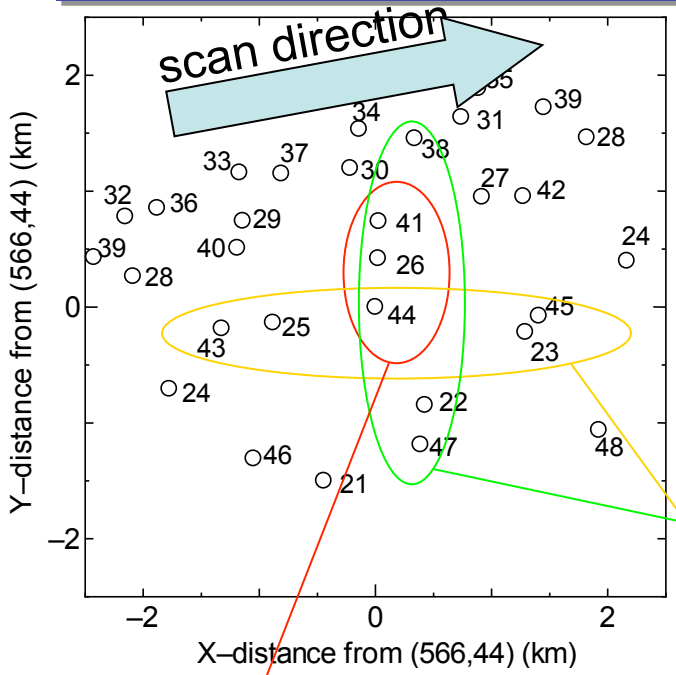
NUBF effect on surface echo profile

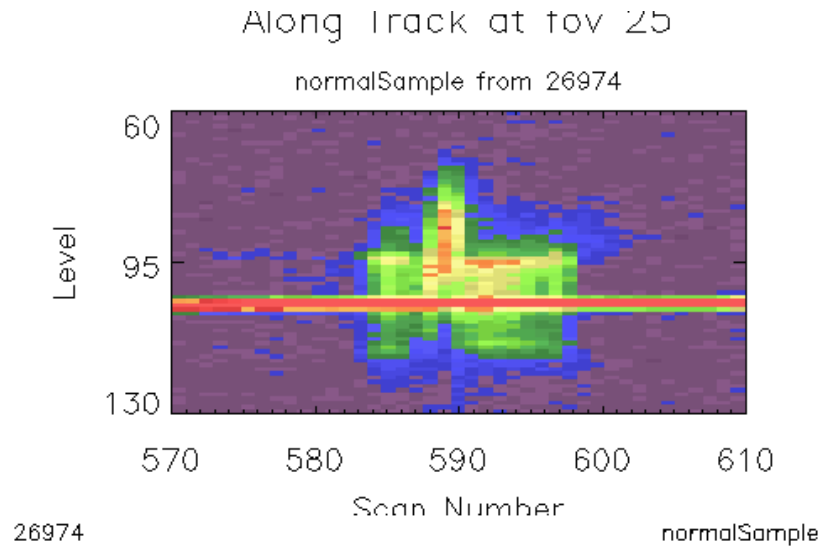
- Comparison of surface echo profile among different locations and incident angles

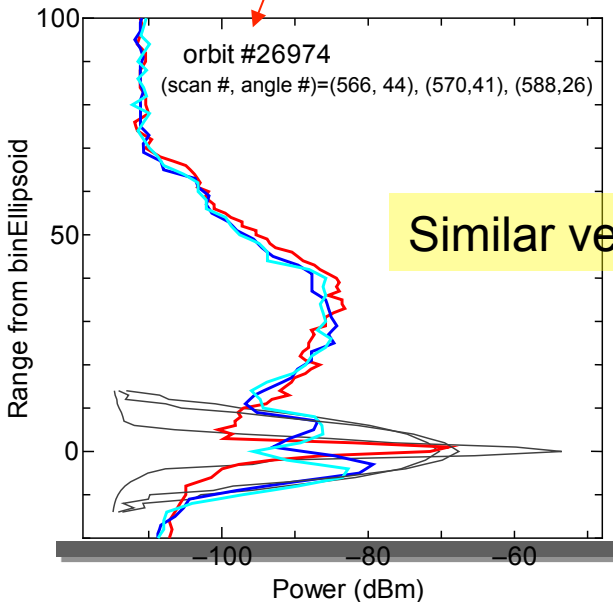


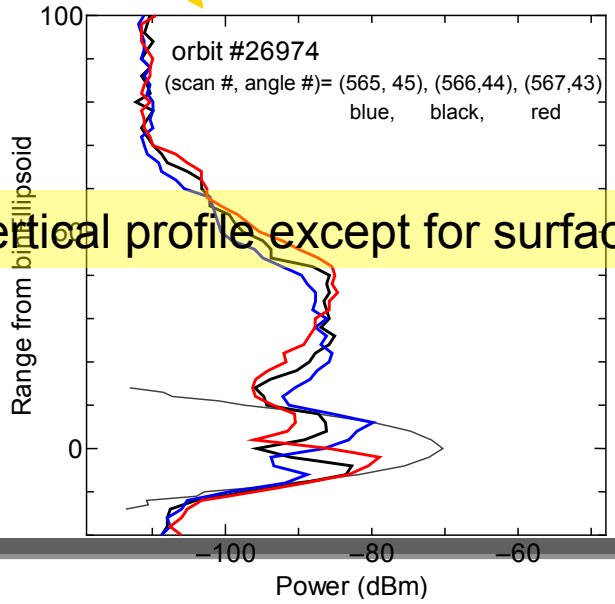
Surface echo profile provides detailed attenuation **along the scan direction.**
→ insensitive to the non-uniformity parpendicular to the scan direction.

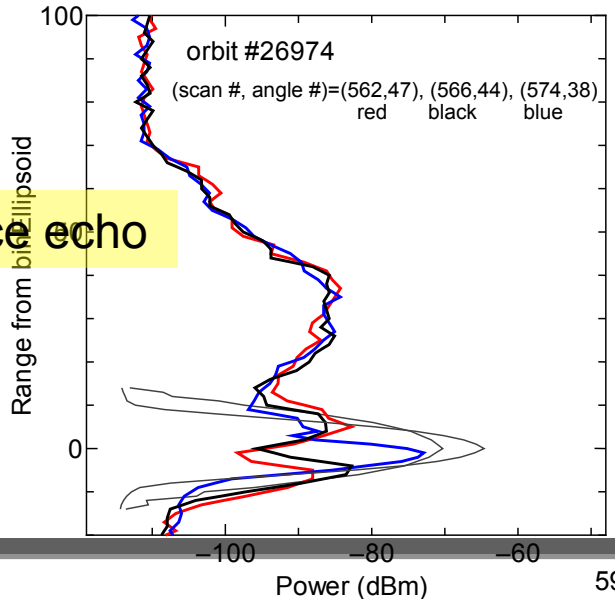
case orbit #26974





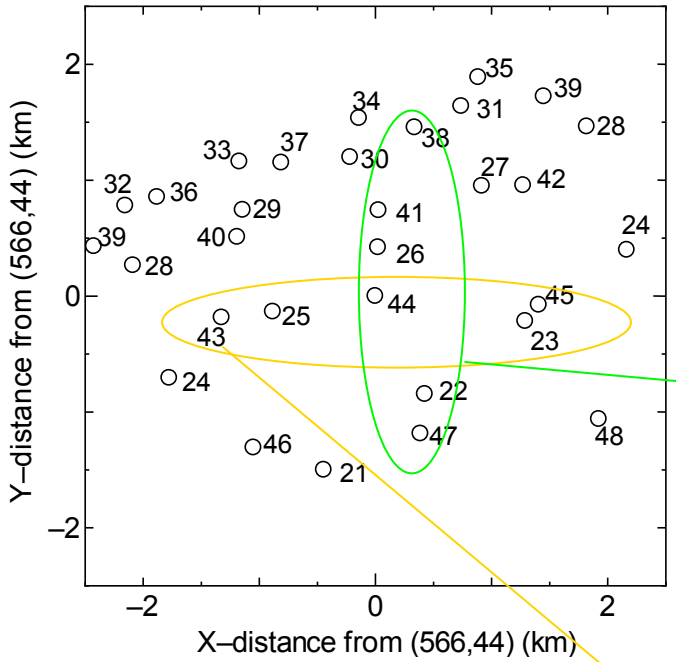




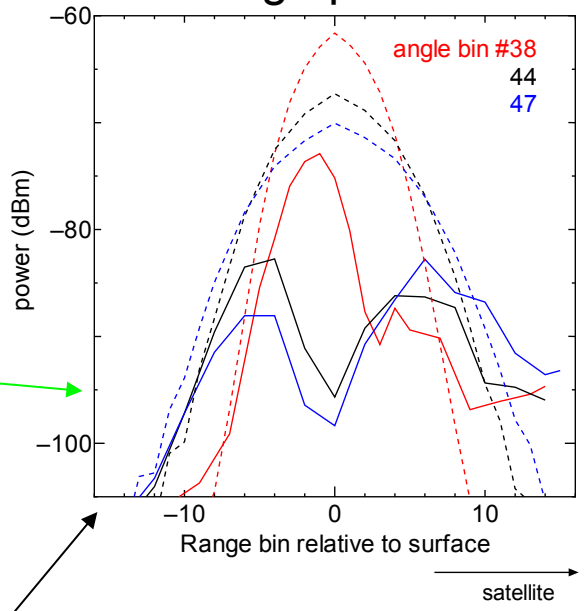


Similar vertical profile except for surface echo

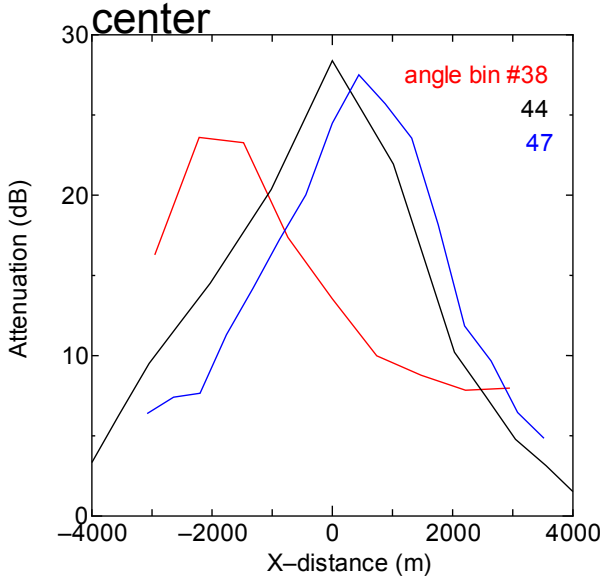
close-up surface echo profile & estimated attenuation



range profile

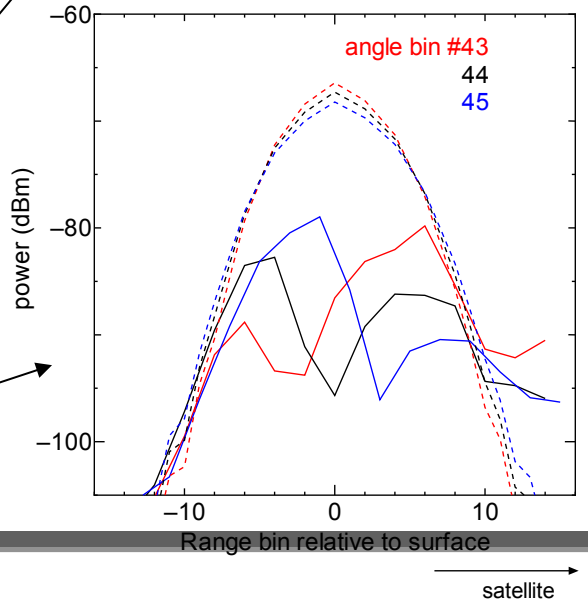


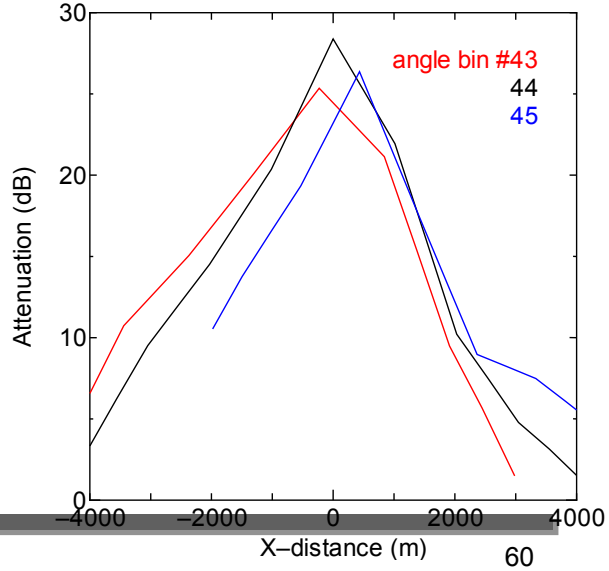
estimated attenuation with correction of beam center



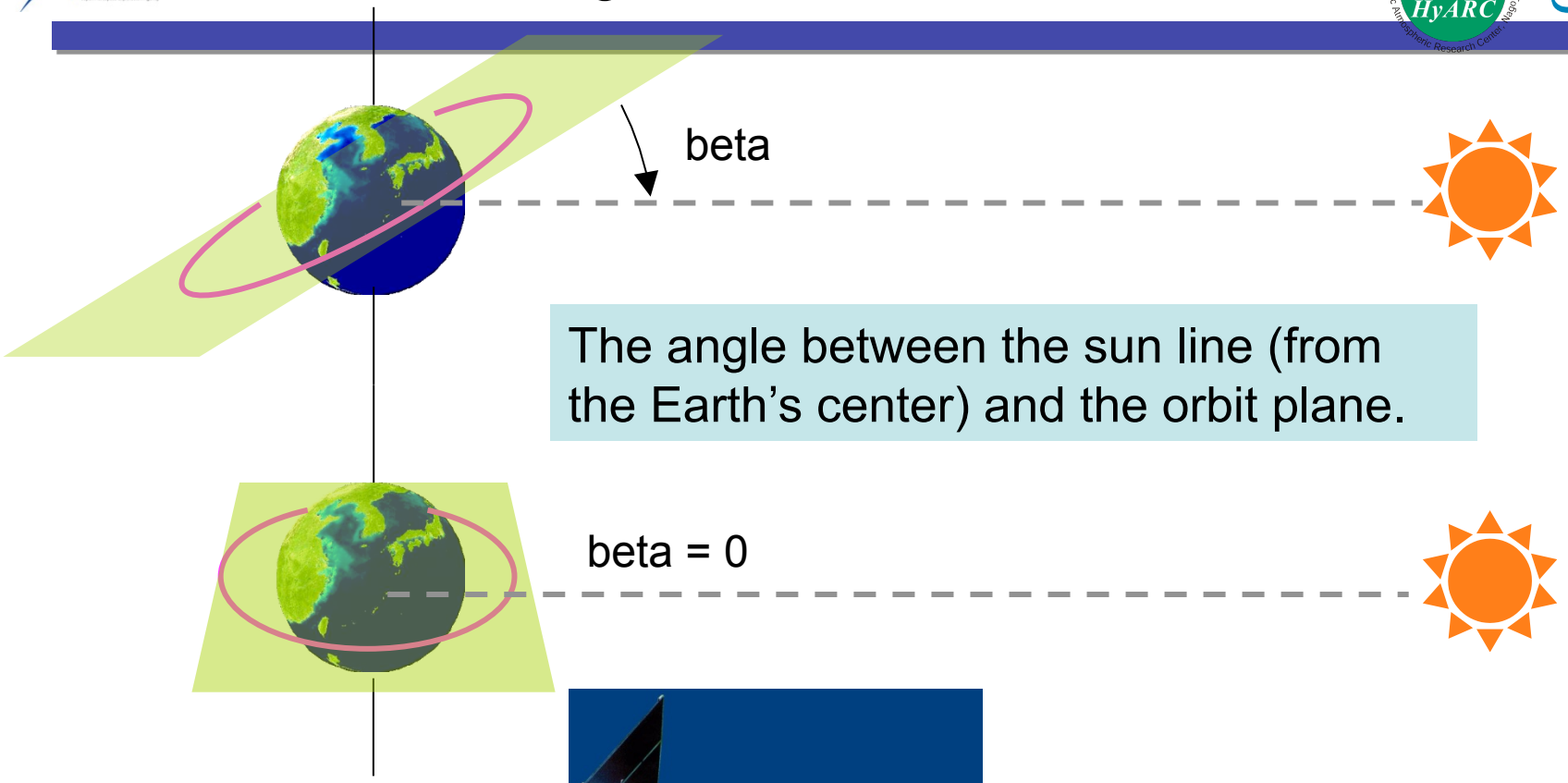
These three foot prints are not on the scan direction. The retrieved attenuation distributions differs, especially angle bin 38, indicating the different echo cell.

These three foot prints are on the scan direction, retrieved attenuation distributions coincides well.

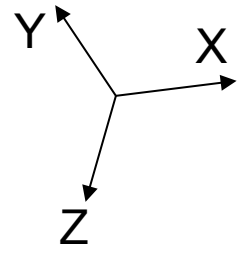




Solar beta angle

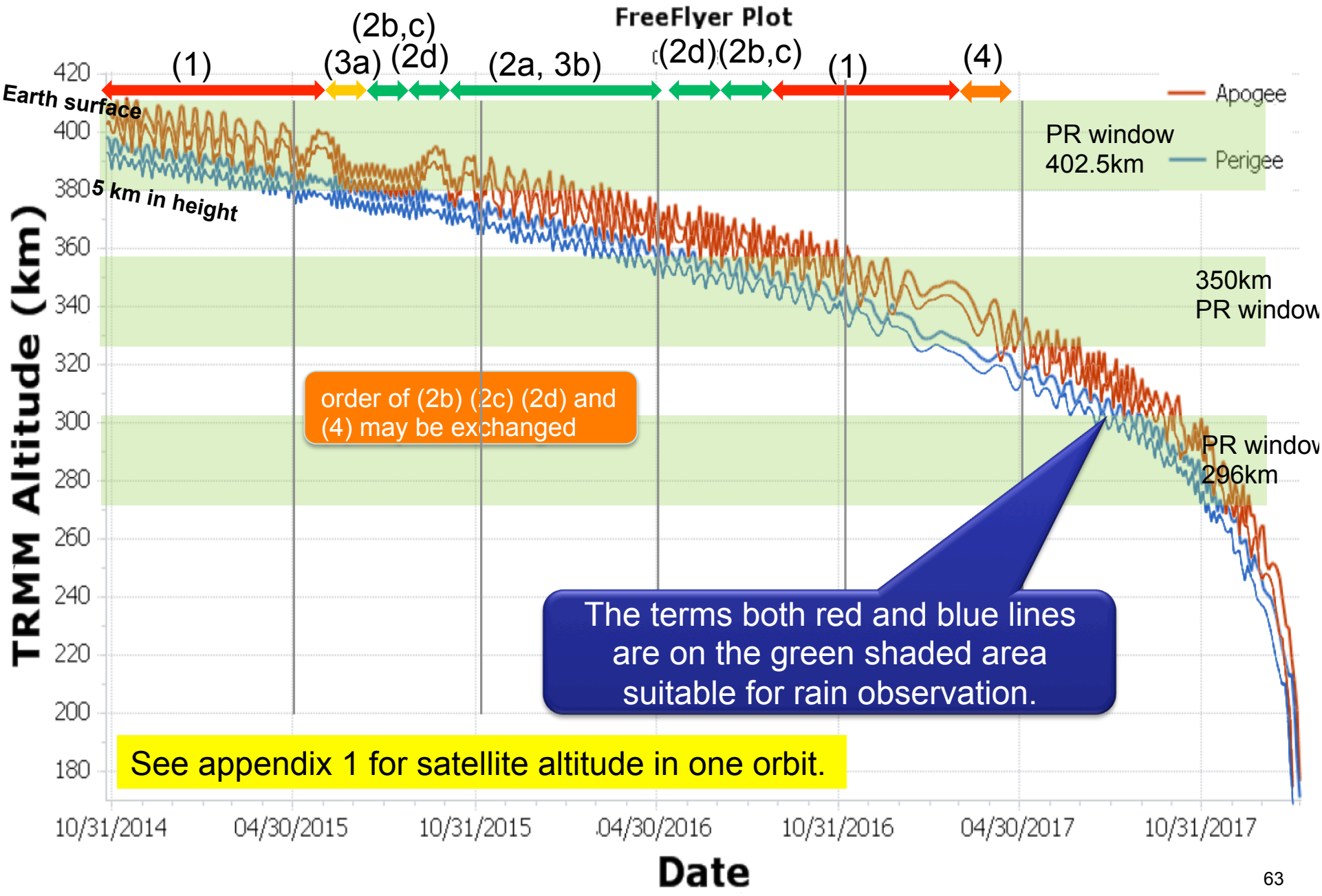


The angle between the sun line (from the Earth's center) and the orbit plane.



- ✓When the beta is equal to zero, sun light illuminates –Z surface of the satellite. (lower temperature in PR)
- ✓Sun light illuminates x- or y- side of the PR for larger beta .angles (higher temperature in PR)

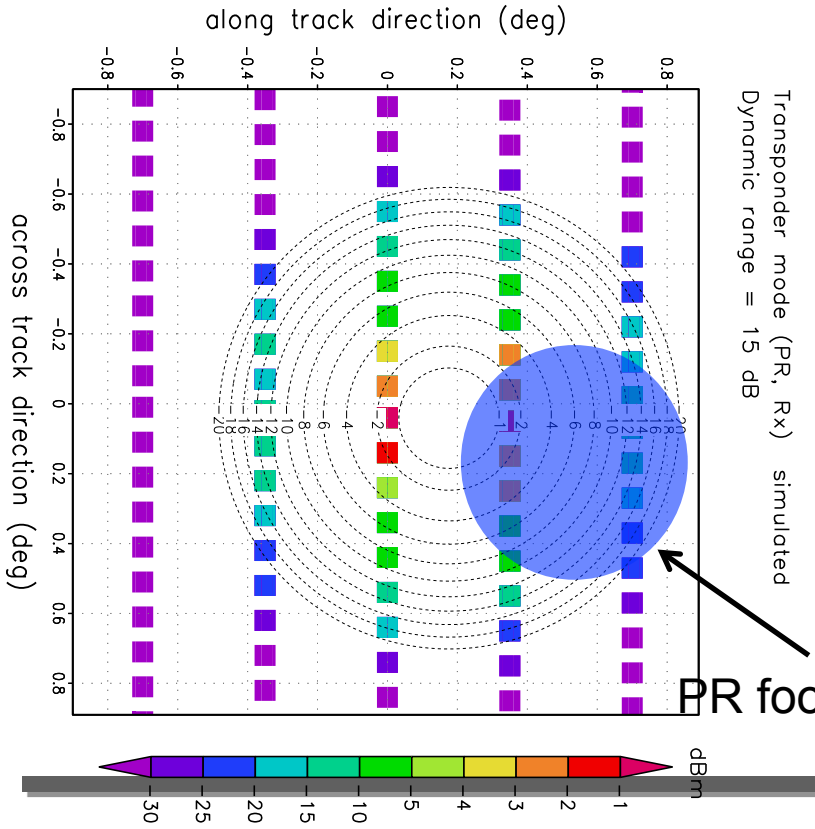
Satellite altitude and experiment schedule



TRMM/PR external cal. obs. vs. KaPR sampling

TRMM
External calibration mode

Squares show the footprint location during external calibration mode, that is **higher sampling density than KaPR interlace observation.**



GPM
KaPR interlace observation